US009468082B2

(12) **United States Patent**
Hayashi et al.

(10) **Patent No.: US 9,468,082 B2**
(45) **Date of Patent: Oct. 11, 2016**

(54) **EXTREME ULTRAVIOLET LIGHT GENERATION APPARATUS AND CONTROL METHOD FOR LASER APPARATUS IN EXTREME ULTRAVIOLET LIGHT GENERATION SYSTEM**

(71) Applicant: **GIGAPHOTON INC.**, Tochigi (JP)

(72) Inventors: **Hideyuki Hayashi**, Oyama (JP); **Kazuhiro Suzuki**, Oyama (JP); **Osamu Wakabayashi**, Oyama (JP)

(73) Assignee: **GIGAPHOTON INC.**, Tochigi (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/814,983**

(22) Filed: **Jul. 31, 2015**

(65) **Prior Publication Data**

US 2015/0342015 A1 Nov. 26, 2015

Related U.S. Application Data

(63) Continuation of application No. 14/290,483, filed on May 29, 2014, now Pat. No. 9,131,589.

(30) **Foreign Application Priority Data**

May 31, 2013 (JP) 2013-114964

(51) **Int. Cl.**

H05G 2/00	(2006.01)
H01S 3/10	(2006.01)
H01S 3/00	(2006.01)
H01S 3/23	(2006.01)

(52) **U.S. Cl.**

CPC ***H05G 2/008*** (2013.01); ***H01S 3/005*** (2013.01); ***H01S 3/10015*** (2013.01); ***H05G 2/006*** (2013.01); *H01S 3/10038* (2013.01); *H01S 3/2316* (2013.01)

(58) **Field of Classification Search**

CPC H01S 3/005; H01S 3/10015; H01S 3/10038; H01S 3/2316; H05G 2/006; H05G 2/008

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,855,943 B2		2/2005	Shields	
7,068,367 B2		6/2006	Stobrawa et al.	
7,589,337 B2		9/2009	Bykanov et al.	
8,158,960 B2	*	4/2012	Vaschenko	B82Y 10/00 250/504 R
8,502,178 B2	*	8/2013	Moriya	H05G 2/008 250/504 R
2012/0080584 A1		4/2012	Partlo et al.	
2012/0228525 A1	*	9/2012	Moriya	H05G 2/003 250/504 R
2012/0250710 A1	*	10/2012	Yoshino	H01S 3/0057 372/25
2012/0305811 A1	*	12/2012	Wakabayashi	H05G 2/008 250/504 R
2012/0307851 A1	*	12/2012	Hori	H01S 3/2232 372/27
2013/0032735 A1	*	2/2013	Nowak	H01S 3/0085 250/504 R
2014/0098830 A1	*	4/2014	Yabu	H05G 2/005 372/30
2015/0264793 A1	*	9/2015	Wakabayashi	H05G 2/008 250/504 R

* cited by examiner

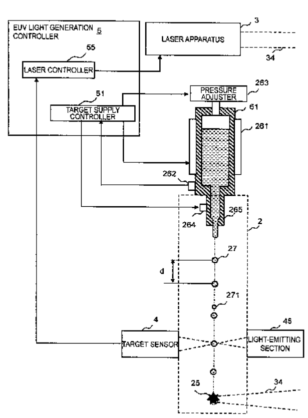
Primary Examiner — Wyatt Stoffa

(74) *Attorney, Agent, or Firm* — Studebaker & Brackett PC

(57) **ABSTRACT**

An extreme ultraviolet light generation apparatus may include a chamber containing a plasma generation region irradiated by a pulse laser beam from a laser apparatus, a target supply device configured to supply a plurality of targets consecutively to the plasma generation region in the chamber, a target detection unit configured to detect a target outputted from the target supply device, and a laser controller configured to control the laser apparatus; the laser controller generating a light emission trigger instructing a laser device included in the laser apparatus to emit a pulse laser beam, and outputting the generated light emission trigger to the laser apparatus, in accordance with a detection signal from the target detection unit; and the laser controller adjusting generation of the light emission trigger outputted consecutively to the laser apparatus so that a time interval of the light emission trigger is within a predetermined range.

19 Claims, 14 Drawing Sheets



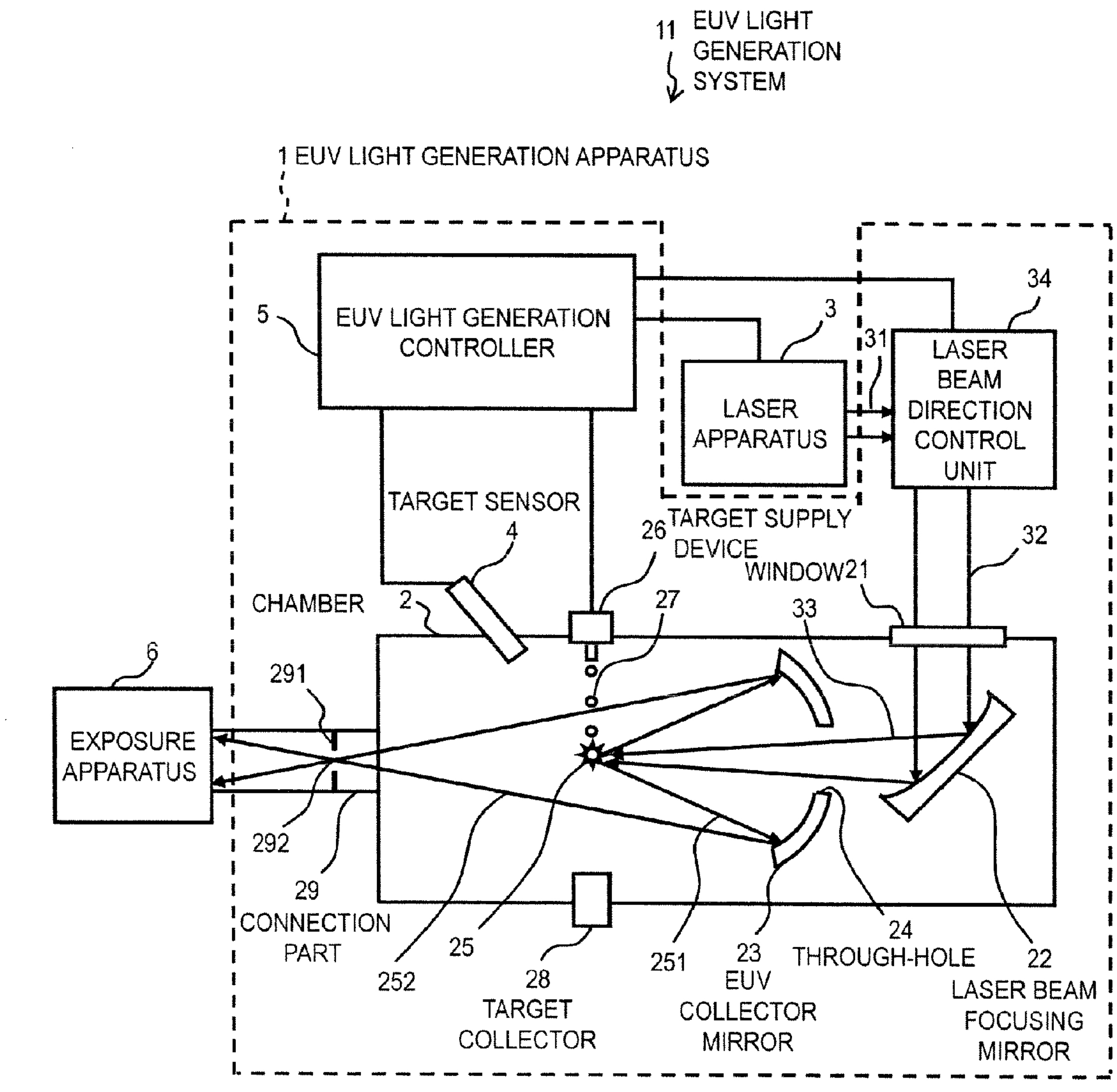
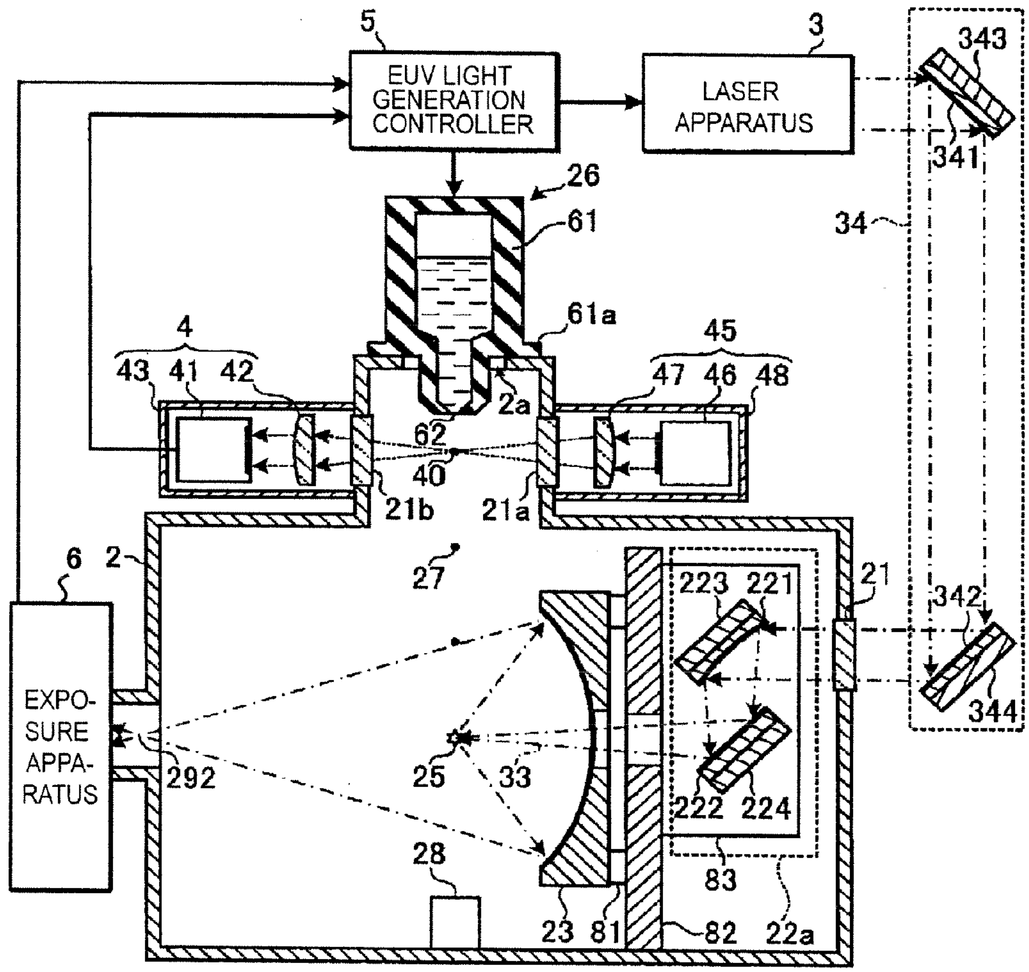

11 EUV LIGHT GENERATION SYSTEM
1 EUV LIGHT GENERATION APPARATUS
5
EUV LIGHT GENERATION CONTROLLER
3
34
31
LASER APPARATUS
LASER BEAM DIRECTION CONTROL UNIT
TARGET SENSOR
4
TARGET SUPPLY DEVICE
26
WINDOW21
32
CHAMBER
2
27
33
6
291
EXPOSURE APPARATUS
292
29
CONNECTION PART
252
25
28
TARGET COLLECTOR
251
23
EUV COLLECTOR MIRROR
24
THROUGH-HOLE
22
LASER BEAM FOCUSING MIRROR

Fig. 1



5
EUV LIGHT GENERATION CONTROLLER
3
LASER APPARATUS
343
341
34
26
61
61a
4
43
41
42
2a
45
47
46
48
62
40
21b
21a
6
2
27
21
223
221
342
344
EXPOSURE APPARATUS
292
25
33
222
224
83
28
23
81
82
22a

Fig. 2

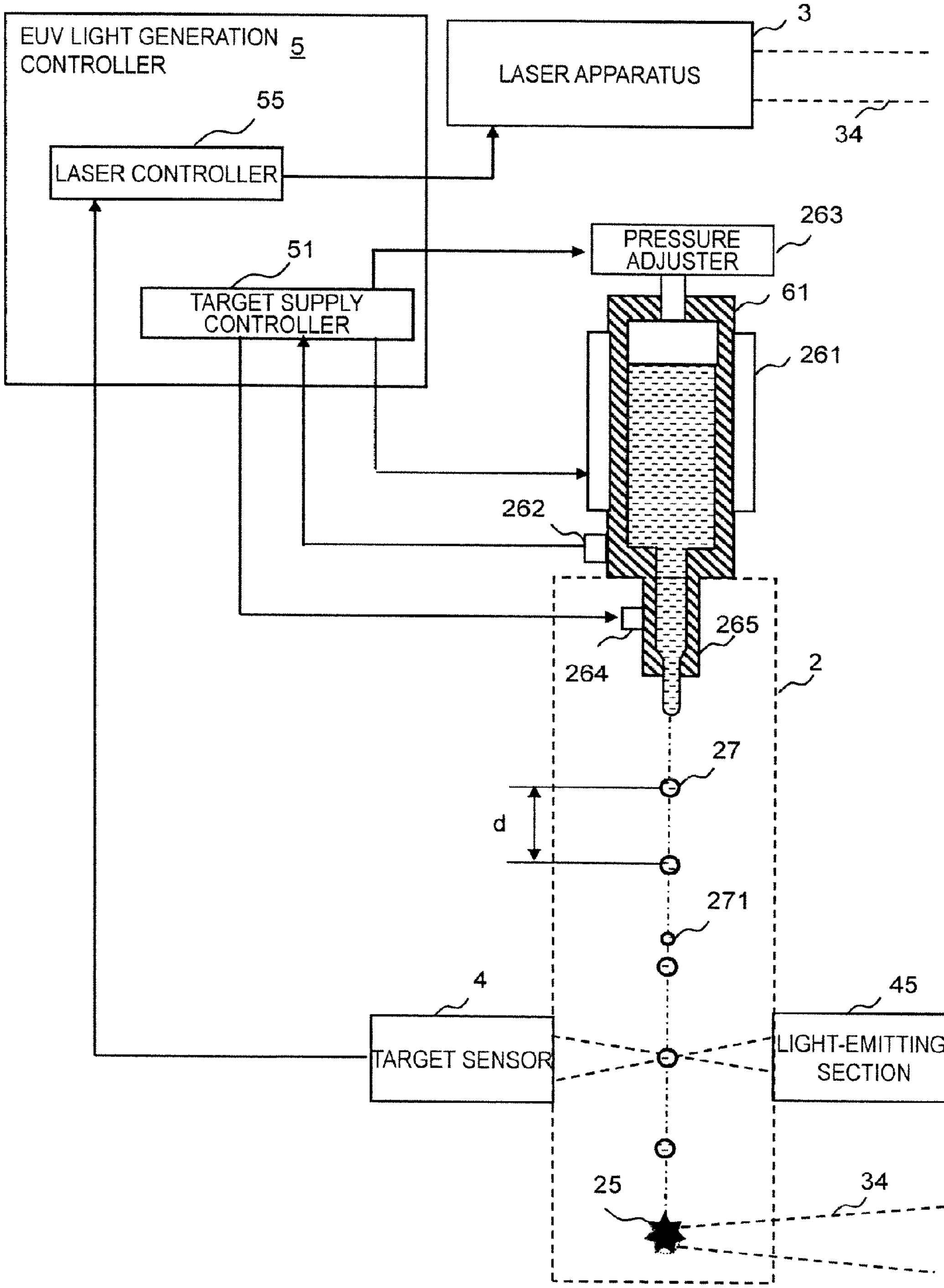

EUV LIGHT GENERATION CONTROLLER
5
55
LASER CONTROLLER
51
TARGET SUPPLY CONTROLLER
LASER APPARATUS
3
34
PRESSURE ADJUSTER
263
61
261
262
265
264
2
27
d
271
4
TARGET SENSOR
45
LIGHT-EMITTING SECTION
25
34

Fig. 3

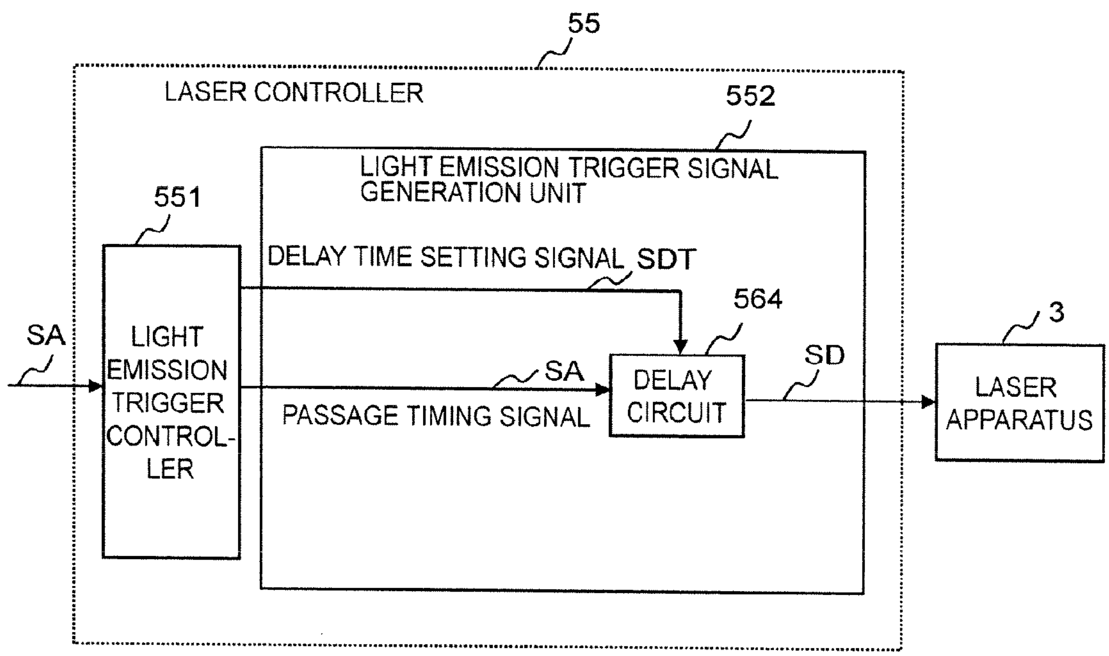

55
LASER CONTROLLER
552
LIGHT EMISSION TRIGGER SIGNAL GENERATION UNIT
551
DELAY TIME SETTING SIGNAL SDT
564
3
SA
LIGHT EMISSION TRIGGER CONTROL-LER
SA
DELAY CIRCUIT
SD
LASER APPARATUS
PASSAGE TIMING SIGNAL

Fig. 4

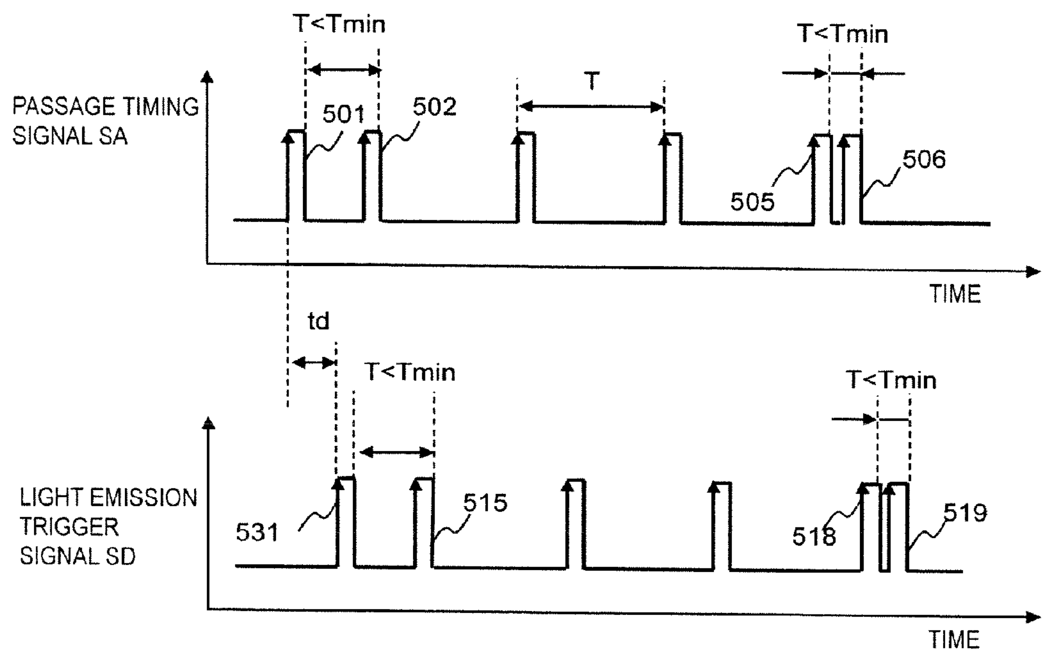

T<Tmin
T<Tmin
PASSAGE TIMING
SIGNAL SA
501
502
T
505
506
TIME
td
T<Tmin
T<Tmin
LIGHT EMISSION
TRIGGER
SIGNAL SD
531
515
518
519
TIME

Fig. 5A

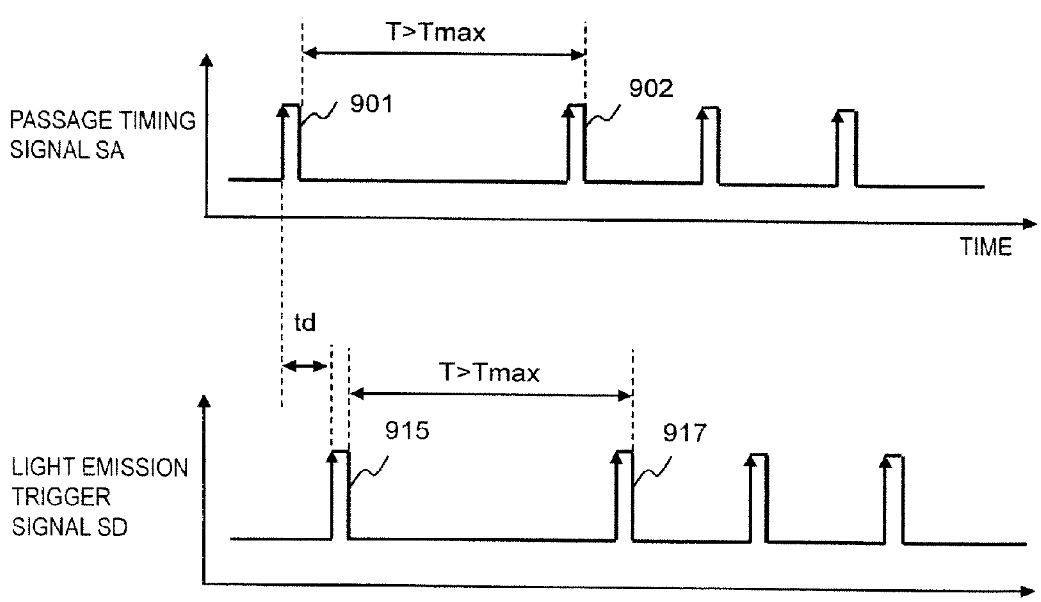
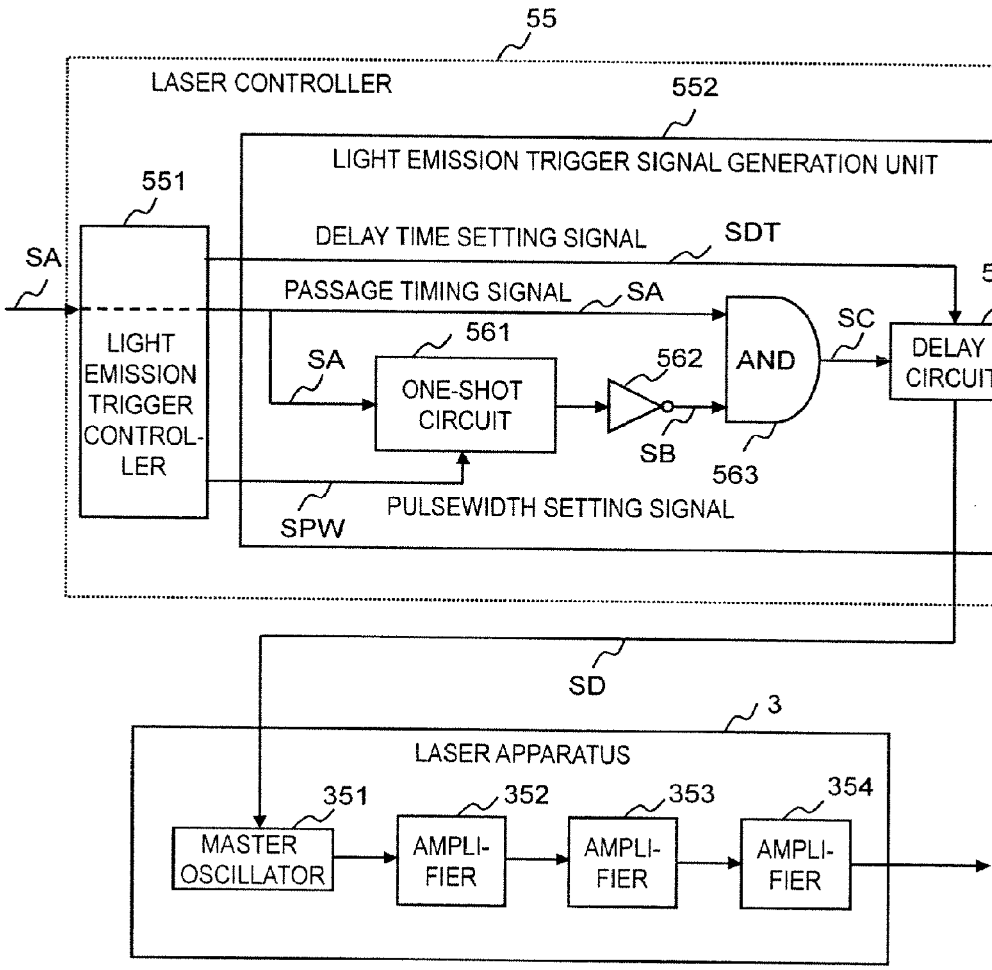
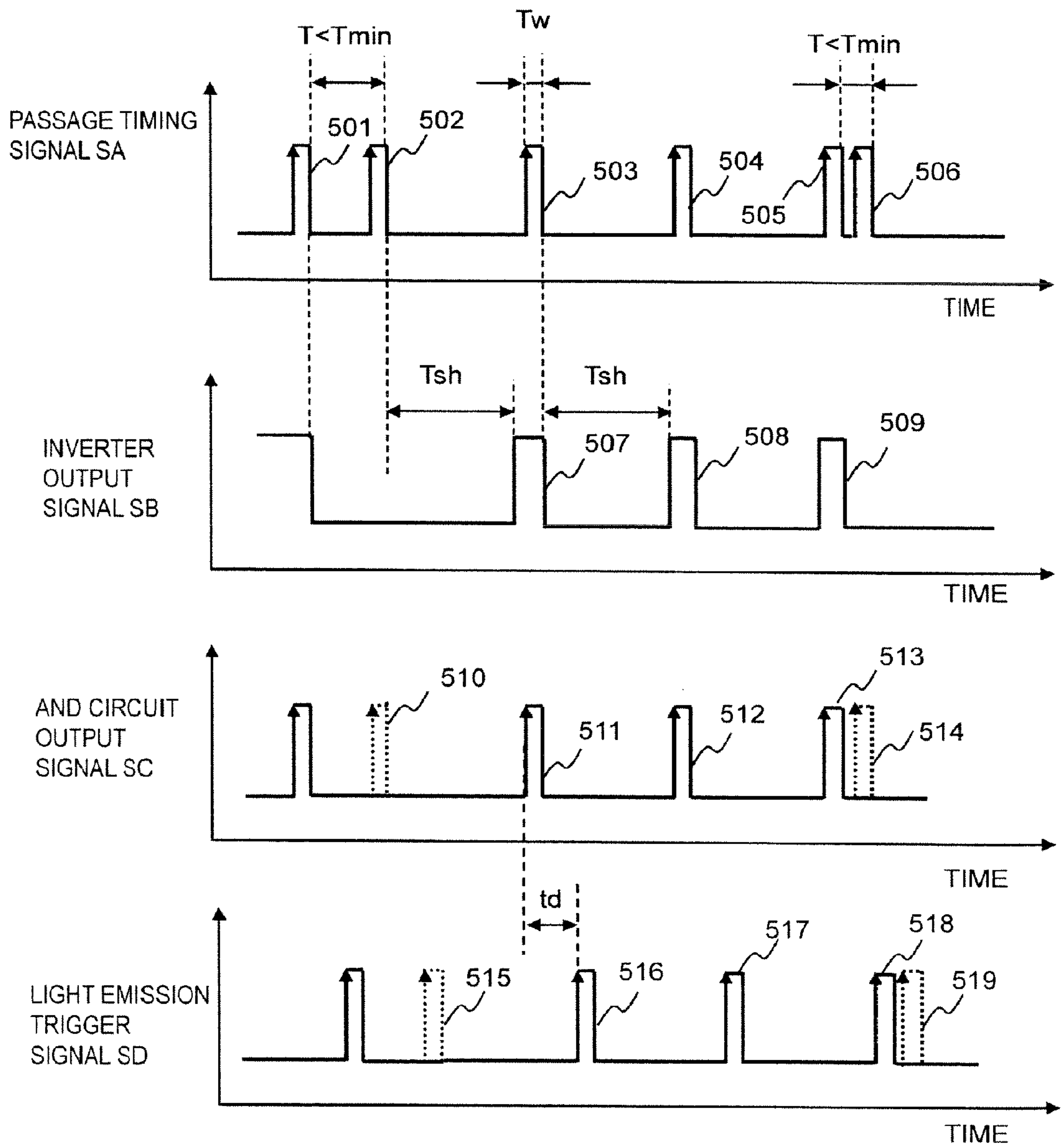

T>Tmax
PASSAGE TIMING
SIGNAL SA
901
902
TIME
td
T>Tmax
915
917
LIGHT EMISSION
TRIGGER
SIGNAL SD
TIME

Fig. 5B



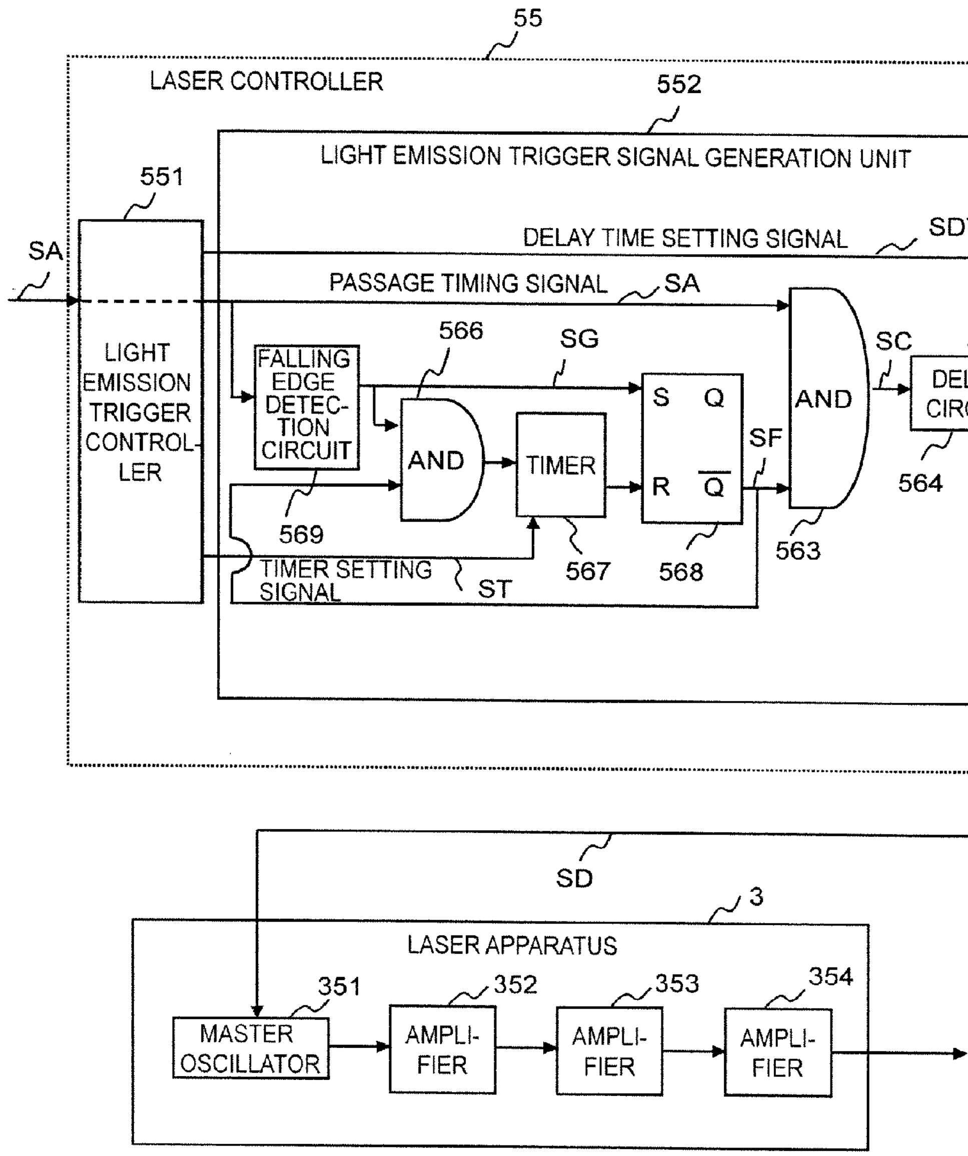
55
LASER CONTROLLER
552
LIGHT EMISSION TRIGGER SIGNAL GENERATION UNIT
551
SA
LIGHT EMISSION TRIGGER CONTROL-LER
DELAY TIME SETTING SIGNAL
SDT
PASSAGE TIMING SIGNAL
SA
564
SA
561
ONE-SHOT CIRCUIT
562
AND
SC
DELAY CIRCUIT
SB
563
SPW
PULSEWIDTH SETTING SIGNAL
SD
3
LASER APPARATUS
351
MASTER OSCILLATOR
352
AMPLI-FIER
353
AMPLI-FIER
354
AMPLI-FIER

Fig. 6



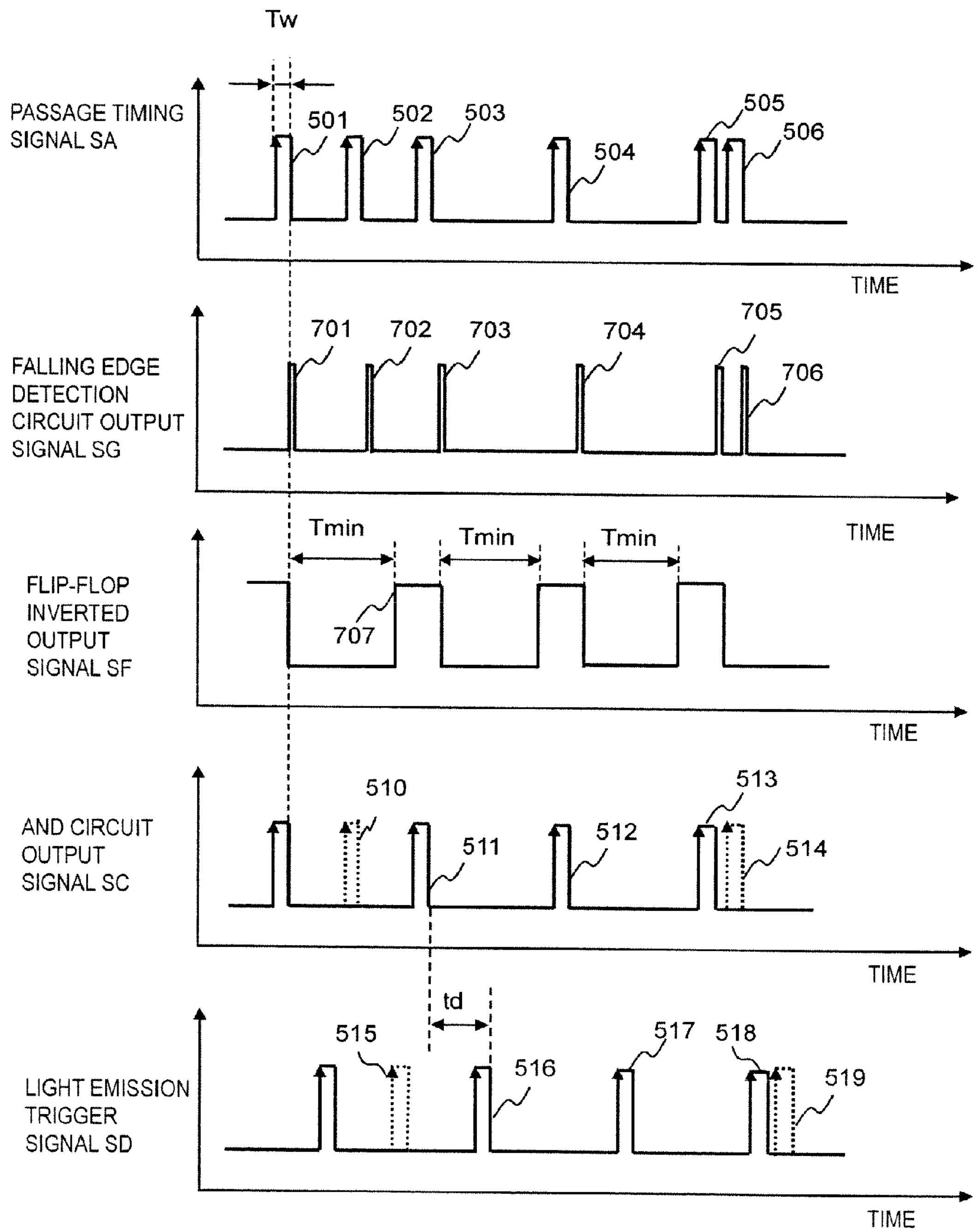
T<Tmin
Tw
T<Tmin
PASSAGE TIMING SIGNAL SA
501
502
503
504
505
506
TIME
Tsh
Tsh
INVERTER OUTPUT SIGNAL SB
507
508
509
TIME
AND CIRCUIT OUTPUT SIGNAL SC
510
511
512
513
514
TIME
td
LIGHT EMISSION TRIGGER SIGNAL SD
515
516
517
518
519
TIME

Fig. 7



55
LASER CONTROLLER
552
LIGHT EMISSION TRIGGER SIGNAL GENERATION UNIT
551
SA
LIGHT EMISSION TRIGGER CONTROLLER
DELAY TIME SETTING SIGNAL
SDT
PASSAGE TIMING SIGNAL
SA
566
SG
SC
FALLING EDGE DETECTION CIRCUIT
AND
TIMER
S
Q
R
Q
SF
AND
DELAY CIRCUIT
564
569
567
568
563
TIMER SETTING SIGNAL
ST
SD
3
LASER APPARATUS
351
352
353
354
MASTER OSCILLATOR
AMPLIFIER
AMPLIFIER
AMPLIFIER

Fig. 8



Tw
PASSAGE TIMING SIGNAL SA
501
502
503
504
505
506
TIME
FALLING EDGE DETECTION CIRCUIT OUTPUT SIGNAL SG
701
702
703
704
705
706
TIME
Tmin
Tmin
Tmin
FLIP-FLOP INVERTED OUTPUT SIGNAL SF
707
TIME
AND CIRCUIT OUTPUT SIGNAL SC
510
511
512
513
514
TIME
td
LIGHT EMISSION TRIGGER SIGNAL SD
515
516
517
518
519
TIME

Fig. 9

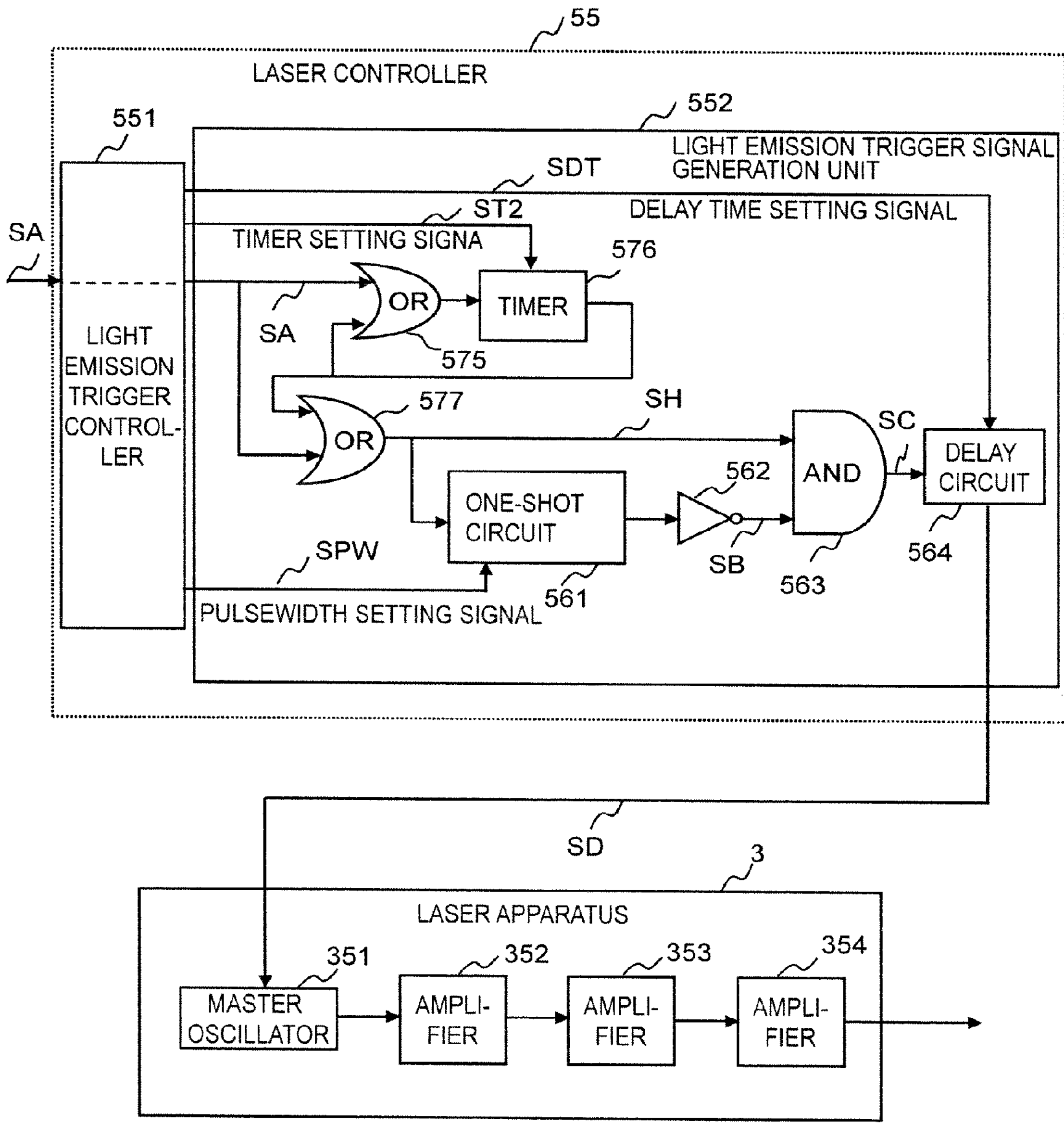

55
LASER CONTROLLER
551
552
LIGHT EMISSION TRIGGER SIGNAL GENERATION UNIT
SDT
ST2
DELAY TIME SETTING SIGNAL
TIMER SETTING SIGNA
SA
576
OR
TIMER
SA
575
LIGHT EMISSION TRIGGER CONTROL-LER
577
SH
OR
SC
AND
DELAY CIRCUIT
562
ONE-SHOT CIRCUIT
SPW
SB
564
563
561
PULSEWIDTH SETTING SIGNAL
SD
3
LASER APPARATUS
351
352
353
354
MASTER OSCILLATOR
AMPLI-FIER
AMPLI-FIER
AMPLI-FIER

Fig. 10

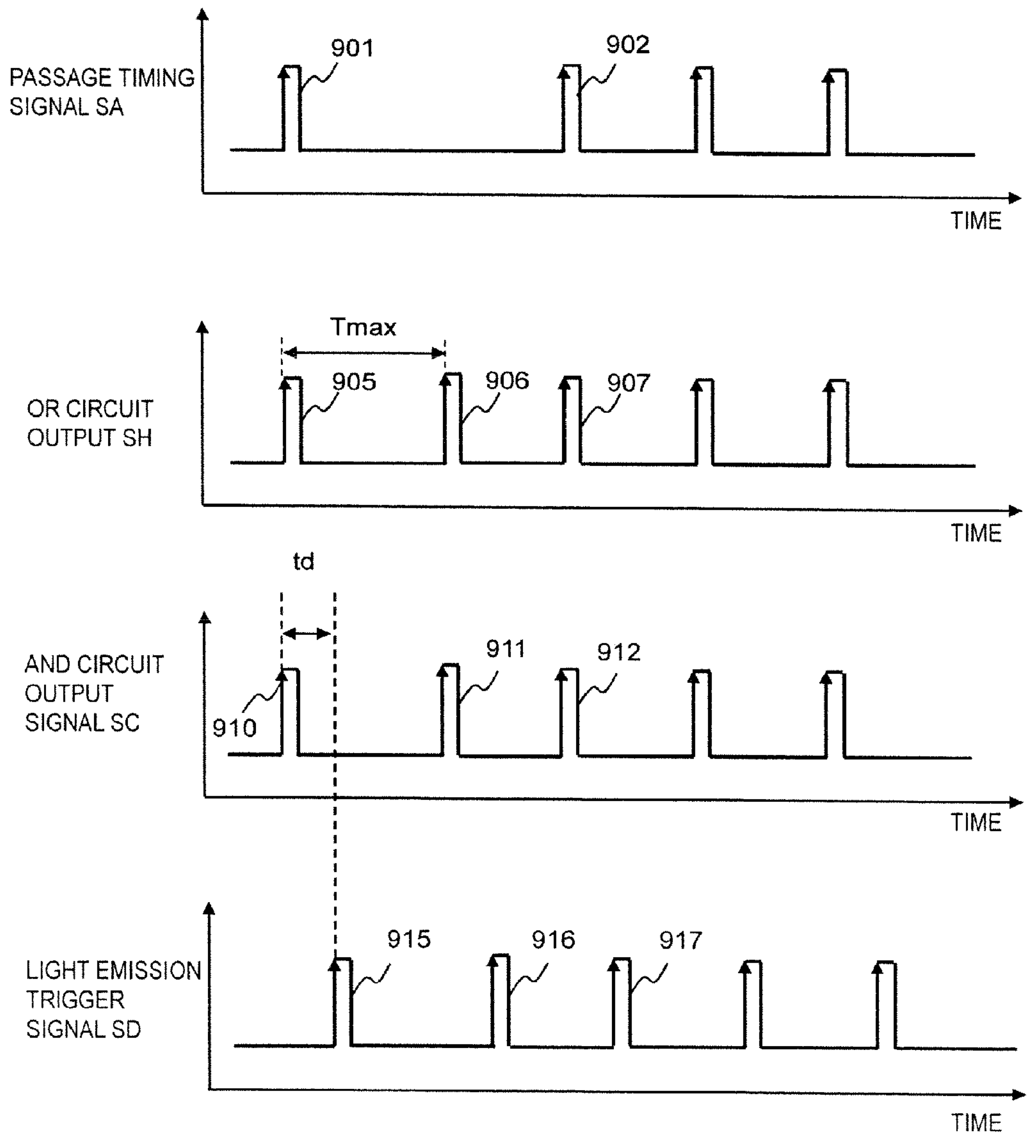

PASSAGE TIMING SIGNAL SA
901
902
TIME
Tmax
OR CIRCUIT OUTPUT SH
905
906
907
TIME
td
AND CIRCUIT OUTPUT SIGNAL SC
910
911
912
TIME
LIGHT EMISSION TRIGGER SIGNAL SD
915
916
917
TIME

Fig. 11

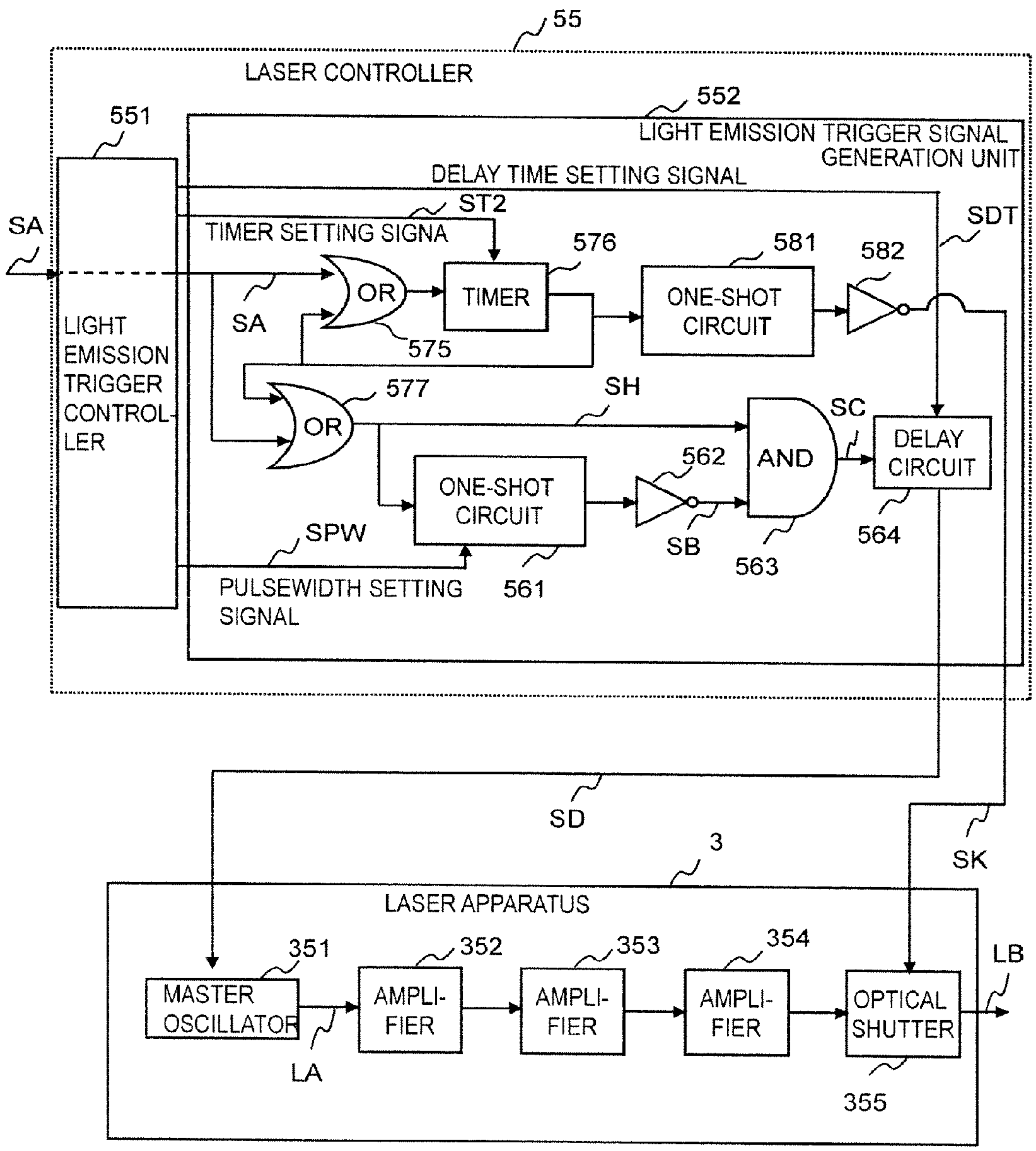

55
LASER CONTROLLER
552
LIGHT EMISSION TRIGGER SIGNAL GENERATION UNIT
551
DELAY TIME SETTING SIGNAL
SA
ST2
TIMER SETTING SIGNA
SDT
576
581
582
OR
TIMER
ONE-SHOT CIRCUIT
SA
575
LIGHT EMISSION TRIGGER CONTROL-LER
577
SH
SC
OR
AND
DELAY CIRCUIT
562
ONE-SHOT CIRCUIT
SPW
SB
564
563
PULSEWIDTH SETTING SIGNAL
561
SD
3
SK
LASER APPARATUS
351
352
353
354
LB
MASTER OSCILLATOR
AMPLI-FIER
AMPLI-FIER
AMPLI-FIER
OPTICAL SHUTTER
LA
355

Fig. 12

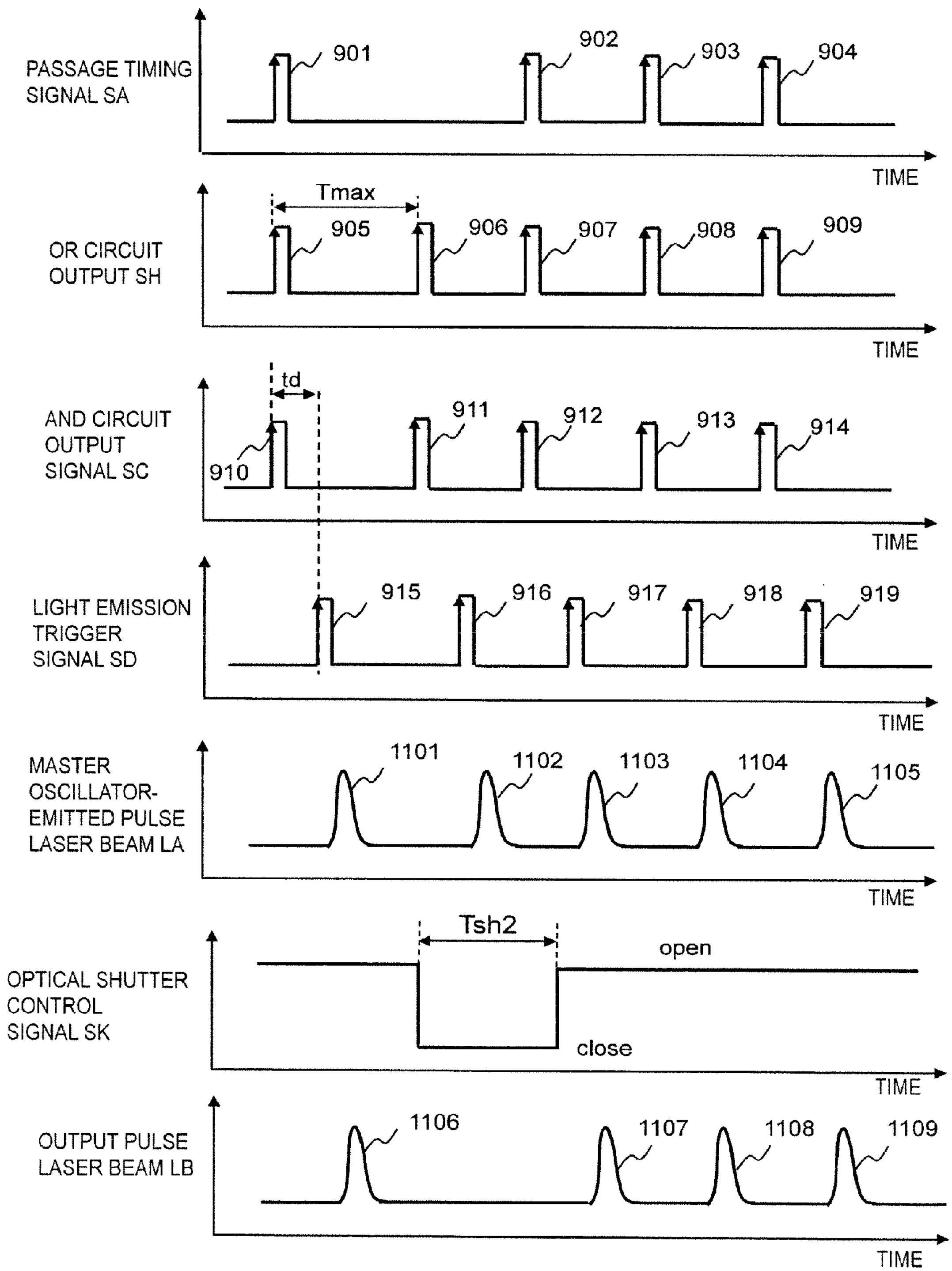

PASSAGE TIMING SIGNAL SA
901
902
903
904
TIME
Tmax
OR CIRCUIT OUTPUT SH
905
906
907
908
909
TIME
td
AND CIRCUIT OUTPUT SIGNAL SC
910
911
912
913
914
TIME
LIGHT EMISSION TRIGGER SIGNAL SD
915
916
917
918
919
TIME
MASTER OSCILLATOR-EMITTED PULSE LASER BEAM LA
1101
1102
1103
1104
1105
TIME
Tsh2
OPTICAL SHUTTER CONTROL SIGNAL SK
open
close
TIME
OUTPUT PULSE LASER BEAM LB
1106
1107
1108
1109
TIME

Fig. 13

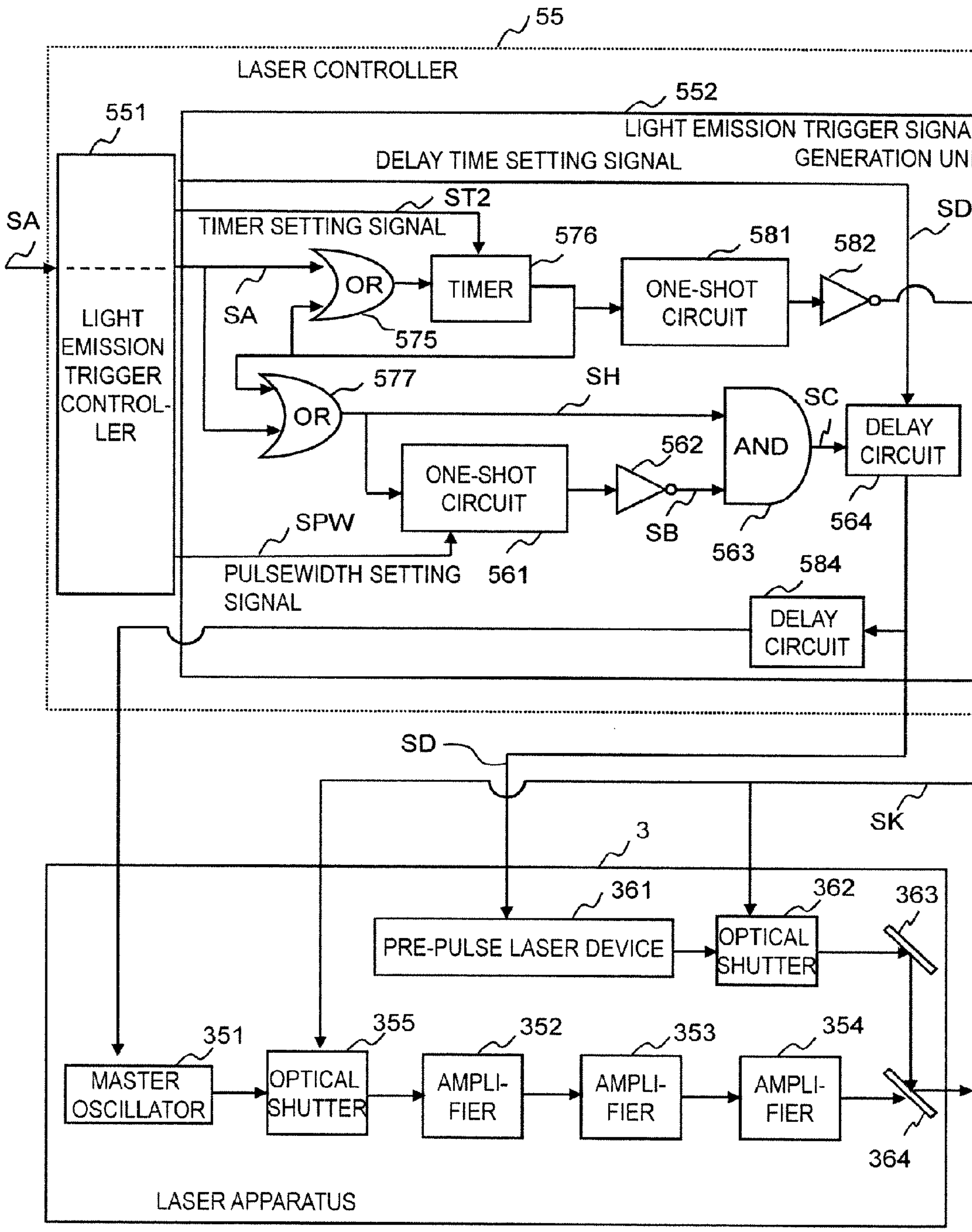

55
LASER CONTROLLER
552
LIGHT EMISSION TRIGGER SIGNAL GENERATION UNIT
551
DELAY TIME SETTING SIGNAL
ST2
SA
TIMER SETTING SIGNAL
SDT
576
581
582
OR
TIMER
ONE-SHOT CIRCUIT
SA
575
LIGHT EMISSION TRIGGER CONTROL-LER
577
SH
SC
OR
DELAY CIRCUIT
562
AND
ONE-SHOT CIRCUIT
SB
564
SPW
563
PULSEWIDTH SETTING SIGNAL
561
584
DELAY CIRCUIT
SD
SK
3
361
362
363
PRE-PULSE LASER DEVICE
OPTICAL SHUTTER
351
355
352
353
354
MASTER OSCILLATOR
OPTICAL SHUTTER
AMPLI-FIER
AMPLI-FIER
AMPLI-FIER
364
LASER APPARATUS

Fig. 14

EXTREME ULTRAVIOLET LIGHT GENERATION APPARATUS AND CONTROL METHOD FOR LASER APPARATUS IN EXTREME ULTRAVIOLET LIGHT GENERATION SYSTEM

CROSS-REFERENCE TO A RELATED APPLICATION

The present application claims priority from Japanese Patent Application No. 2013-114964, filed May 31, 2013.

BACKGROUND

1. Technical Field

The present disclosure relates to apparatuses for generating extreme ultraviolet light and to control methods for laser apparatuses in extreme ultraviolet light generation systems.

2. Related Art

In recent years, semiconductor production processes have become capable of producing semiconductor devices with increasingly fine feature sizes, as photolithography has been making rapid progress toward finer fabrication. In the next generation of semiconductor production processes, microfabrication with feature sizes at 60 nm to 45 nm, and further, microfabrication with feature sizes of 32 nm or less will be required. In order to meet the demand for microfabrication with feature sizes of 32 nm or less, for example, an exposure apparatus is needed in which a system for generating EUV light at a wavelength of approximately 13 nm is combined with a reduced projection reflective optical system.

Three kinds of systems for generating EUV light are known in general, which include a Laser Produced Plasma (LPP) type system in which plasma is generated by irradiating a target material with a laser beam, a Discharge Produced Plasma (DPP) type system in which plasma is generated by electric discharge, and a Synchrotron Radiation (SR) type system in which orbital radiation is used to generate plasma.

SUMMARY

An extreme ultraviolet light generation apparatus according to one aspect of the present disclosure may be an extreme ultraviolet light generation apparatus that generates extreme ultraviolet light by irradiating a target with a pulse laser beam and producing plasma. The extreme ultraviolet light generation apparatus may include a chamber, a target supply device, a target detection unit, and a laser controller. The chamber may contain a plasma generation region irradiated by a pulse laser beam from a laser apparatus. The target supply device may be configured to supply a plurality of targets consecutively to the plasma generation region in the chamber. The target detection unit may be configured to detect a target outputted from the target supply device that has passed a predetermined position between the target supply device and the plasma generation region. The laser controller may be configured to control the laser apparatus. The laser controller may generate a light emission trigger instructing a laser device included in the laser apparatus to emit a pulse laser beam, and may output the generated light emission trigger to the laser apparatus, in accordance with a detection signal from the target detection unit indicating that a target has been detected. The laser controller may adjust generation of the light emission trigger outputted consecutively to the laser apparatus so that a time interval of the light emission trigger is within a predetermined range.

BRIEF DESCRIPTION OF THE DRAWINGS

Hereinafter, selected embodiments of the present disclosure will be described with reference to the accompanying drawings.

FIG. **1** schematically illustrates an exemplary configuration of an LPP type EUV light generation system.

FIG. **2** is a partial cross-sectional view illustrating the configuration of an EUV light generation system.

FIG. **3** is a block diagram illustrating control of a target supply device and a laser apparatus performed by an EUV light generation controller.

FIG. **4** schematically illustrates a comparative example of the configuration of a laser controller.

FIG. **5**A illustrates an example of timing charts indicating signals from a light emission trigger signal generation unit indicated in FIG. **4**.

FIG. **5**B illustrates an example of timing charts indicating signals from a light emission trigger signal generation unit indicated in FIG. **4**.

FIG. **6** schematically illustrates an example of the configuration of a laser controller and a laser apparatus according to a first embodiment.

FIG. **7** illustrates an example of timing charts indicating signals from a light emission trigger signal generation unit indicated in FIG. **6**, according to the first embodiment.

FIG. **8** schematically illustrates another example of the configuration of a laser controller and a laser apparatus according to the first embodiment.

FIG. **9** illustrates an example of timing charts indicating signals from a light emission trigger signal generation unit indicated in FIG. **8**, according to the first embodiment.

FIG. **10** schematically illustrates an example of the configuration of a laser controller and a laser apparatus according to a second embodiment.

FIG. **11** illustrates an example of timing charts indicating signals from a light emission trigger signal generation unit according to the second embodiment.

FIG. **12** schematically illustrates an example of the configuration of a laser controller and a laser apparatus according to a third embodiment.

FIG. **13** illustrates an example of timing charts indicating signals from a light emission trigger signal generation unit and a pulse laser beam in a laser apparatus according to the third embodiment.

FIG. **14** schematically illustrates an example of the configuration of a laser controller and a laser apparatus according to a fourth embodiment.

DETAILED DESCRIPTION

Hereinafter, selected embodiments of the present disclosure will be described in detail with reference to the accompanying drawings. The embodiments to be described below are merely illustrative in nature and do not limit the scope of the present disclosure. Further, the configuration(s) and operation(s) described in each embodiment are not all essential in implementing the present disclosure. Note that like elements are referenced by like reference numerals and characters, and duplicate descriptions thereof will be omitted herein.

Contents

1. Overview

In an LPP type EUV light generation system, a target supply device may output a target and cause the target to reach a plasma generation region within a chamber. By a laser device irradiating the target with a pulse laser beam at the point in time when the target reaches the plasma generation region, the target can be turned into plasma and EUV light can be radiated from the plasma.

In the EUV light generation system, it can be required that EUV light be generated over a predetermined time at a predetermined repetition rate. The predetermined repetition rate may be 100 kHz, for example. The target supply device may output the targets at the stated predetermined repetition rate in order for the EUV light generation system to generate the EUV light at the predetermined repetition rate.

The EUV light generation system may include a sensor for detecting the targets outputted from the target supply device between the target supply device and the plasma generation region. The sensor may measure the timing at which the targets pass. The EUV light generation system may output a pulse laser beam from the laser apparatus in synchronization with the timing at which the targets are detected by the sensor, and may irradiate the targets with the pulse laser beam.

By detecting the targets that pass through a predetermined position and outputting a light emission trigger to the laser apparatus in accordance with the timing at which the targets pass, the EUV light generation system can irradiate the targets with the pulse laser beam with a high level of precision at the point in time when the targets reach the plasma generation region.

However, the generation of the targets outputted from the target supply device can become unstable. Accordingly, a time interval over which the targets are outputted can become longer or shorter than a predetermined range. Meanwhile, satellites can be generated when the targets are generated by the target supply device. "Satellites" are small droplets that have separated from the original target, and can be mistakenly detected as targets by the sensor. Furthermore, in the case where the target material contains foreign objects, a flow rate of the target material can temporarily drop when such foreign objects traverse the interior of a nozzle.

As a result, a time interval over which the pulse laser beam is outputted can become longer or shorter. In the case with a time interval over which the pulse laser beam is outputted is shorter than a predetermined range, the energy of the pulse laser beam can drop and the pulse waveform can become distorted. This can lead to a problem in that the target will not be turned into plasma correctly. Furthermore, in the case where the time interval over which the pulse laser beam is outputted is shorter than the predetermined range, laser oscillation can become unstable and the laser apparatus can be damaged.

On the other hand, in the case where a time interval over which the pulse laser beam is outputted is longer than the predetermined range, the energy of the pulse laser beam can rise and the pulse waveform can become distorted. This can cause greater fluctuations to occur in the energy of the EUV light.

According to one aspect of the present disclosure, an EUV light generation apparatus may generate and output a light emission trigger that instructs a laser device included in a laser apparatus to emit a pulse laser beam in accordance with a detection signal from a target detection unit indicating that a target has been detected. The EUV light generation apparatus may adjust generation of the light emission trigger outputted consecutively to the laser apparatus so that a time interval of the light emission trigger is within a predetermined range.

2. Terms

Terms used in the present application will be described hereinafter. A "plasma generation region" can refer to a region where the generation of plasma for generating EUV light begins. It can be necessary for a target to be supplied to the plasma generation region and for a pulse laser beam to be focused at the plasma generation region at the timing at which the target reaches the plasma generation region in order for the generation of plasma to begin at the plasma generation region. A "light emission trigger" can be a signal instructing a laser device that generates and emits (outputs) a laser beam to emit the laser beam. A "light emission trigger signal" can be a signal that contains the light emission trigger and that changes over time.

3. Overview of EUV Light Generation System

3.1 Configuration

FIG. **1** schematically illustrates an exemplary configuration of an LPP type EUV light generation system. An EUV light generation apparatus **1** may be used with at least one laser apparatus **3**. Hereinafter, a system that includes the EUV light generation apparatus **1** and the laser apparatus **3** may be referred to as an EUV light generation system **11**. As shown in FIG. **1** and described in detail below, the EUV light generation system **11** may include a chamber **2** and a target supply device **26**. The chamber **2** maybe sealed airtight. The target supply device **26** may be mounted onto the chamber **2**, for example, to penetrate a wall of the chamber **2**. A target material to be supplied by the target supply device **26** may include, but is not limited to, tin, terbium, gadolinium, lithium, xenon, or any combination thereof.

The chamber **2** may have at least one through-hole or opening formed in its wall, and a pulse laser beam **32** may travel through the through-hole/opening into the chamber **2**. Alternatively, the chamber **2** may have a window **21**, through which the pulse laser beam **32** may travel into the chamber **2**. An EUV collector mirror **23** having a spheroidal surface may, for example, be provided in the chamber **2**. The EUV collector mirror **23** may have a multi-layered reflective film formed on the spheroidal surface thereof. The reflective film may include a molybdenum layer and a silicon layer, which are alternately laminated. The EUV collector mirror **23** may have a first focus and a second focus, and may be positioned such that the first focus lies in a plasma generation region **25** and the second focus lies in an intermediate focus (IF) region **292** defined by the specifications of an external apparatus, such as an exposure apparatus **6**. The

EUV collector mirror **23** may have a through-hole **24** formed at the center thereof so that a pulse laser beam **33** may travel through the through-hole **24** toward the plasma generation region **25**.

The EUV light generation system **11** may further include an EUV light generation controller **5** and a target sensor **4**. The target sensor **4** may have an imaging function and detect at least one of the presence, trajectory, position, and speed of a target **27**.

Further, the EUV light generation system **11** may include a connection part **29** for allowing the interior of the chamber **2** to be in communication with the interior of the exposure apparatus **6**. A wall **291** having an aperture **293** may be provided in the connection part **29**. The wall **291** may be positioned such that the second focus of the EUV collector mirror **23** lies in the aperture **293** formed in the wall **291**.

The EUV light generation system **11** may also include a laser beam direction control unit **34**, a laser beam focusing mirror **22**, and a target collector **28** for collecting targets **27**. The laser beam direction control unit **34** may include an optical element (not separately shown) for defining the direction into which the pulse laser beam **32** travels and an actuator (not separately shown) for adjusting the position and the orientation or posture of the optical element.

3.2 Operation

With continued reference to FIG. **1**, a pulse laser beam **31** outputted from the laser apparatus **3** may pass through the laser beam direction control unit **34** and be outputted therefrom as the pulse laser beam **32** after having its direction optionally adjusted. The pulse laser beam **32** may travel through the window **21** and enter the chamber **2**. The pulse laser beam **32** may travel inside the chamber **2** along at least one beam path from the laser apparatus **3**, be reflected by the laser beam focusing mirror **22**, and strike at least one target **27** as a pulse laser beam **33**.

The target supply device **26** may be configured to output the target(s) **27** toward the plasma generation region **25** in the chamber **2**. The target **27** may be irradiated with at least one pulse of the pulse laser beam **33**. Upon being irradiated with the pulse laser beam **33**, the target **27** may be turned into plasma, and rays of light **251** including EUV light may be emitted from the plasma. At least the EUV light included in the light **251** may be reflected selectively by the EUV collector mirror **23**. EUV light **252**, which is the light reflected by the EUV collector mirror **23**, may travel through the intermediate focus region **292** and be outputted to the exposure apparatus **6**. Here, the target **27** may be irradiated with multiple pulses included in the pulse laser beam **33**.

The EUV light generation controller **5** may be configured to integrally control the EUV light generation system **11**. The EUV light generation controller **5** may be configured to process image data of the target **27** captured by the target sensor **4**. Further, the EUV light generation controller **5** may be configured to control at least one of: the timing when the target **27** is outputted and the direction into which the target **27** is outputted. Furthermore, the EUV light generation controller **5** may be configured to control at least one of: the timing when the laser apparatus **3** oscillates, the direction in which the pulse laser beam **33** travels, and the position at which the pulse laser beam **33** is focused. It will be appreciated that the various controls mentioned above are merely examples, and other controls may be added as necessary.

4. Control of Target Supply Device and Laser Apparatus in EUV Light Generation System

4.1 Configuration of EUV Light Generation System

FIG. **2** is a partial cross-sectional view illustrating the configuration of the EUV light generation system. As shown in FIG. **2**, a laser beam focusing optical system **22***a*, the EUV collector mirror **23**, the target collector **28**, an EUV collector mirror holder **81**, and plates **82** and **83** may be provided within the chamber **2**.

The plate **82** may be anchored to the chamber **2**. The plate **83** may be anchored to the plate **82**. The EUV collector mirror **23** may be anchored to the plate **82** via the EUV collector mirror holder **81**.

The laser beam focusing optical system **22***a* may include an off-axis paraboloid mirror **221**, a flat mirror **222**, and holders **223** and **224**. The off-axis paraboloid mirror **221** and the flat mirror **222** may be held by the holders **223** and **224**, respectively. The holders **223** and **224** may be anchored to the plate **83**.

The positions and orientations of the off-axis paraboloid mirror **221** and the flat mirror **222** may be held so that the pulse laser beam **33** reflected by those mirrors is focused at the plasma generation region **25**. The target collector **28** may be disposed upon a straight line extending from the trajectory of the target **27**.

The target supply device **26** may be attached to the chamber **2**. The target supply device **26** may include a reservoir **61**. The reservoir **61** may hold a target material that has been melted using a heater **261** shown in FIG. **3**. An opening serving as a nozzle opening **62** may be formed in the reservoir **61**.

Part of the reservoir **61** may be inserted into a through-hole **2***a* formed in a wall surface of the chamber **2** so that the nozzle opening **62** formed in the reservoir **61** is positioned inside the chamber **2**. The target supply device **26** may supply the melted target material to the plasma generation region **25** within the chamber **2** as droplet-shaped targets **27** via the nozzle opening **62**. A flange portion **61***a* of the reservoir **61** may be tightly fitted and anchored to the wall surface of the chamber **2** in the periphery of the through-hole **2***a*.

The target sensor **4** and a light-emitting section **45** may be attached to the chamber **2**. The target sensor **4** may include a photodetector **41**, an image forming optical system **42**, and a receptacle **43**. The receptacle **43** may be anchored to the outside of the chamber **2**, and the photodetector **41** and the image forming optical system **42** may be anchored within the receptacle **43**. The light-emitting section **45** may include a light source **46**, a focusing optical system **47**, and a receptacle **48**.

The receptacle **48** may be anchored to the outside of the chamber **2**, and the light source **46** and the focusing optical system **47** may be anchored within the receptacle **48**. Light outputted from the light source **46** can be focused by the focusing optical system **47**. The focal position of the outputted light may be located substantially upon the trajectory of the targets **27**.

The target sensor **4** and the light-emitting section **45** may be disposed opposite to each other on either side of the trajectory of the targets **27**. Windows **21***a* and **21***b* may be provided in the chamber **2**. The window **21***a* may be positioned between the light-emitting section **45** and the trajectory of the targets **27**.

The light-emitting section **45** may focus light at a predetermined position in the trajectory of the targets **27** via the window **21***a*. The window **21***b* may be positioned between the trajectory of the targets **27** and the target sensor **4**. When the target **27** passes through the focal position of the light emitted from the light-emitting section **45**, the target sensor **4** may detect a change in the light passing through the trajectory of the target **27** and the vicinity thereof and may output a passage timing signal as a target **27** detection signal.

A single detection pulse may be outputted as the passage timing signal each time a single target **27** is detected. The image forming optical system **42** may form, upon a light-receiving surface of the target sensor **4**, an image of the trajectory of the target **27** and the vicinity thereof, in order to improve the accuracy of the detection of the target **27**.

A position of the center of the target **27** detected by the target sensor **4** will be referred to as a target detection position **40** in the following descriptions. In the example shown in FIG. **2**, the target detection position **40** can substantially match the focal position of the light emitted from the light-emitting section **45**.

The laser beam direction control unit **34** and the EUV light generation controller **5** may be provided outside the chamber **2**. The laser beam direction control unit **34** may include high-reflecting mirrors **341** and **342**, as well as holders **343** and **344**. The high-reflecting mirrors **341** and **342** may be held by the holders **343** and **344**, respectively. The high-reflecting mirrors **341** and **342** may conduct the pulse laser beam outputted by the laser apparatus **3** to the laser beam focusing optical system **22*a*** via the window **21**.

The EUV light generation controller **5** may receive an EUV light generation signal from the exposure apparatus **6**. The EUV light generation signal may be a signal instructing the EUV light generation system **11** to generate EUV light during a predetermined time. The EUV light generation controller **5** may carry out control operations for outputting EUV light to the exposure apparatus **6** during the stated predetermined time.

4.2 Operation

FIG. **3** is a block diagram illustrating control of the target supply device **26** and the laser apparatus **3** performed by the EUV light generation controller **5**. The EUV light generation controller **5** may include a target supply controller **51** and a laser controller **55**. The target supply controller **51** may control operations performed by the target supply device **26**. The laser controller **55** may control operations performed by the laser apparatus **3**.

In addition to the reservoir **61** that holds the target material in a melted state, the target supply device **26** may include the heater **261**, a temperature sensor **262**, a pressure adjuster **263**, a piezoelectric element **264**, and a nozzle **265**.

The heater **261** and the temperature sensor **262** may be anchored to the reservoir **61**. The piezoelectric element **264** may be anchored to the nozzle **265**. The nozzle **265** may have the nozzle opening **62**, shown in FIG. **2**, that outputs the target **27**, which is liquid Sn, for example. The pressure adjuster **263** may be provided in a pipe located between an inert gas supply section and the reservoir **61**.

The target supply controller **51** may control the heater **261** based on a value detected by the temperature sensor **262**. For example, the target supply controller **51** may control the heater **261** so that the Sn within the reservoir **61** reaches a predetermined temperature greater than or equal to the melting point of the Sn. As a result, the reservoir **61** can melt the Sn held therewithin. The predetermined temperature may be a temperature of 232° C. to 300° C., for example.

The target supply controller **51** may control a pressure within the reservoir **61** using the pressure adjuster **263**. The pressure adjuster **263** may adjust the pressure within the reservoir **61** under the control of the target supply controller **51** so that the targets **27** reach the plasma generation region **25** at a predetermined velocity.

The target supply controller **51** may send an electrical signal having a predetermined frequency to the piezoelectric element **264**. The piezoelectric element **264** can vibrate in response to the received electrical signal, and can cause the nozzle **265** to vibrate at the stated frequency.

As a result, the droplet-shaped targets **27** can be generated from a jet of the liquid Sn outputted from the nozzle opening **62** as a result of the piezoelectric element **264** causing the nozzle opening **62** to vibrate. This method for generating targets is sometimes referred to as the "continuous jet method". In this manner, the target supply device **26** can supply the droplet-shaped targets **27** to the plasma generation region **25** at a predetermined velocity and a predetermined interval d. At this time, a predetermined time interval T can be calculated using the predetermined velocity and the predetermined interval d.

4.3 Issue

Satellites **271** may be produced when the target supply controller **51** generates the droplet-shaped target **27**. The satellites **271** may be droplets, smaller than the target **27**, that have separated from the original target **27**. The satellites **271** may be located immediately before or immediately after the original target **27** moving toward the plasma generation region **25**. The satellites **271** can be targets that are not desirable.

In addition to the original target **27**, the target sensor **4** may detect the satellites **271** as targets as well, based on the light outputted by the light-emitting section **45**. By detecting the satellites **271** in addition to the original target **27**, the target sensor **4** may output a detection signal indicating that a target has been detected. The detection signal indicating that a target has been detected may be a detection pulse in a passage timing signal SA described below.

The target sensor **4** may output the detection signal indicating that a target has been detected to the laser controller **55**. As described above, the satellites **271** can reduce the time interval of the detection signal. Furthermore, in the case where the target material contains foreign objects, a flow rate of the target material can temporarily drop when such foreign objects traverse the interior of the nozzle **265**, which can increase the output time interval of the targets **27**. Accordingly, the output time interval of the targets **27** from the target supply controller **51** can fluctuate, and the time interval of the detection signal can also fluctuate in response thereto.

FIG. **4** schematically illustrates a comparative example of the configuration of the laser controller **55**. The laser controller **55** may include a light emission trigger controller **551** and a light emission trigger signal generation unit **552**. The light emission trigger signal generation unit **552** may generate a light emission trigger signal SD that is to be inputted to the laser apparatus **3**, and may output the generated signal to the laser apparatus **3**.

The light emission trigger signal generation unit **552** may include a delay circuit **564**. An input of the delay circuit **564** may be connected to the light emission trigger controller **551**, and an output of the delay circuit **564** may be connected to the laser apparatus **3**. The light emission trigger controller **551** may set a delay time td of the delay circuit **564** in accordance with a delay time setting signal SDT. The light emission trigger controller **551** may receive the passage timing signal SA from the target sensor **4** and output the received signal to the light emission trigger signal generation unit **552**.

The delay circuit **564** may receive the passage timing signal SA, generate the light emission trigger signal SD by delaying the passage timing signal SA by the delay time td, and output the light emission trigger signal SD to the laser apparatus **3**. The light emission trigger signal SD may contain a light emission trigger that instructs a laser device included in the laser apparatus **3** to emit a pulse laser beam. The light emission trigger may be a light emission trigger pulse, which is a pulse signal.

FIGS. **5**A and **5**B are examples of timing charts indicating signals from the light emission trigger signal generation unit **552**. Specifically, FIGS. **5**A and **5**B are examples of timing charts indicating the passage timing signal SA and the light emission trigger signal SD from the delay circuit **564**, respectively. As shown in FIGS. **5**A and **5**B, each pulse in the light emission trigger signal SD can be delayed from the corresponding pulses in the passage timing signal SA by the delay time td.

In the case where the targets **27** are being supplied correctly, the time interval T of the detection pulses in the passage timing signal SA can be within a predetermined range. In other words, Tmin≤T≤Tmax can hold true. The light emission trigger pulses in the light emission trigger signal SD can also be generated at the same cycle. The predetermined range for the time interval T of the detection pulse will be referred to as a "permissible range" hereinafter.

However, as described above, the time interval T of the detection pulses in the passage timing signal SA can become shorter than Tmin or longer than Tmax due to target generation abnormalities occurring as a result of satellites being produced, the presence of foreign objects, and so on.

For example, in FIG. **5**A, the time interval T between a pulse **501** and a pulse **502** in the passage timing signal can be less than Tmin. Likewise, the time interval T between a pulse **505** and a pulse **506** can be less than Tmin. Due to the time interval of the pulses in the passage timing signal SA, the time interval T between a pulse **531** and a pulse **515** in the light emission trigger signal SD can be less than Tmin. Furthermore, the time interval T between a pulse **518** and a pulse **519** can be less than Tmin.

In FIG. **5**B, the time interval T between a detection pulse **901** and a detection pulse **902** can be greater than Tmax. Due to the time interval of the pulses in the passage timing signal SA, the time interval T between a light emission trigger pulse **915** and a light emission trigger pulse **917** can be greater than Tmax.

As described above, in the case where the time interval of the light emission trigger supplied to the laser apparatus **3** is outside the permissible range (Tmin≤T≤Tmax), the energy and waveform of the pulse laser beam outputted from the laser apparatus **3** to the plasma generation region **25** may change, and the energy of the EUV light may change greatly as a result. The light emission trigger signal generation unit **552** according to the present disclosure can generate the light emission trigger signal SD so that the output interval of the light emission trigger is within the permissible range, as will be described hereinafter.

5. Control of Light Emission Triggers to Laser Device

5.1 First Embodiment

Configuration

FIG. **6** schematically illustrates an example of the configuration of the laser controller **55** and the laser apparatus **3** according to the first embodiment. The laser controller **55** according to the present embodiment may, in the case where the time interval of sequential first and second detection pulses in the passage timing signal SA is less than a predetermined time, forego outputting a light emission trigger pulse corresponding to the second detection pulse. Through this, fluctuations in the pulse laser beam caused by a master oscillator **351** in the laser apparatus **3** having a short light emission interval can be suppressed.

The laser controller **55** may include the light emission trigger controller **551** and the light emission trigger signal generation unit **552**. The light emission trigger signal generation unit **552** may include a one-shot circuit **561**, an inverter **562**, an AND circuit **563**, and the delay circuit **564**. The light emission trigger signal generation unit **552** may generate the light emission trigger signal SD and output the generated signal to the laser apparatus **3**.

The light emission trigger controller **551** may control the generation of the light emission trigger signal SD. The light emission trigger controller **551** may set a pulsewidth Tsh of the one-shot circuit **561** via a pulsewidth setting signal SPW. The light emission trigger controller **551** may set the delay time td of the delay circuit **564** in accordance with the delay time setting signal SDT. The light emission trigger controller **551** may receive the passage timing signal SA from the target sensor **4**. Alternatively, the light emission trigger signal generation unit **552** may receive the passage timing signal SA without using the light emission trigger controller **551**.

An input of the one-shot circuit **561** may be connected to an output of the light emission trigger controller **551**. The one-shot circuit **561** may receive the passage timing signal SA from the light emission trigger controller **551**. The one-shot circuit **561** may output a pulse signal having the pulsewidth Tsh in response to a falling edge of the input signal. An input of the inverter **562** may be connected to an output of the one-shot circuit **561**.

One input of the AND circuit **563** may be connected to an output of the inverter **562**. Another input of the AND circuit **563** may be connected to an output of the light emission trigger controller **551**. The AND circuit **563** may receive the passage timing signal SA from the light emission trigger controller **551**. An input of the delay circuit **564** may be connected to an output of the AND circuit **563**. The delay circuit **564** may output the light emission trigger signal SD to the laser apparatus **3**. Details of the signals SA to SD in the light emission trigger signal generation unit **552** will be given later.

The laser apparatus **3** may include the master oscillator **351** as well as a first amplifier **352**, a second amplifier **353**, and a third amplifier **354**. The master oscillator **351** can be a laser device that generates and outputs a pulse laser beam. The master oscillator **351**, the first amplifier **352**, the second amplifier **353**, and the third amplifier **354** may be connected in series. The master oscillator **351** may be a CO_2 laser including a Q switch. The amplifiers **352** to **354** may be amplifiers that contain CO_2 laser gas. The number of amplifiers can depend on the design. The amplifiers **352** to **354** may be omitted.

Operation

Referring to FIG. **6**, the light emission trigger controller **551** may receive the passage timing signal SA from the target sensor **4**, and may output the received signal to the one-shot circuit **561** and the AND circuit **563**. For example, the one-shot circuit **561** may output a pulse having the pulsewidth Tsh at the falling edge of the passage timing signal SA. In other words, the one-shot circuit **561** may detect a timing at which the passage timing signal SA changes from ON, which is a high-level, to OFF, which is a low-level, and may generate a pulse indicating the timing of that detection.

The inverter **562** may receive the signal outputted from the one-shot circuit **561**, and may generate an output signal SB by inverting the received signal. The output signal SB from the inverter **562** may be inputted to the AND circuit **563**.

The AND circuit **563** may receive the passage timing signal SA from the light emission trigger controller **551** and the output signal SB from the inverter **562**. The AND circuit **563** may generate an AND signal SC from the received passage timing signal SA and the inverter output signal SB. The AND signal SC outputted from the AND circuit **563** can be ON when both the input signals SA and SB are ON, and can be OFF when at least one of the input signals is OFF.

The AND circuit **563** may output the AND signal SC to the delay circuit **564**. The delay circuit **564** may generate the light emission trigger signal SD based on the AND signal SC and may output the generated signal to the master oscillator **351**. The delay circuit **564** may output the light emission trigger signal SD, which has been generated by delaying the received AND signal SC by the delay time td.

The light emission trigger signal SD may be a signal in which the prescribed delay time td has been applied to the AND signal SC. The delay time td can be a delay time that causes the pulse laser beam to be focused at the plasma generation region **25** at the timing at which the target **27** detected by the target sensor **4** reaches the plasma generation region **25**.

The delay time td can be applied using the following formula, for example.

$$td=L/v-\alpha$$

L may represent a distance from the target detection position **40** to a center position of the plasma generation region **25**. v may represent a velocity of the target **27**. α may represent an amount of time from when the light emission trigger instructing the laser apparatus **3** to emit the pulse laser beam is outputted to when the pulse laser beam is focused at the plasma generation region **25**.

The master oscillator **351** of the laser apparatus **3** may receive the light emission trigger signal SD from the delay circuit **564** of the laser controller **55**. The master oscillator **351** may output the pulse laser beam in accordance with the light emission trigger signal SD. The master oscillator **351** may output the pulse laser beam in response to, for example, the falling edge of the pulse in the light emission trigger signal SD. The pulse of the light emission trigger signal can serve as the light emission trigger instructing the master oscillator **351** to emit (output) the pulse laser beam.

The pulse laser beam outputted from the master oscillator **351** may be amplified by the first amplifier **352**. The pulse laser beam amplified by and outputted from the first amplifier **352** may be further amplified by the second amplifier **353**, and the pulse laser beam amplified by and outputted from the second amplifier **353** may be further amplified by the third amplifier **354**.

FIG. **7** is an example of timing charts indicating signals in the light emission trigger signal generation unit **552**. This timing chart example indicates relationships among the signals in the light emission trigger signal generation unit **552**. Specifically, FIG. **7** illustrates timing charts for the passage timing signal SA, the output signal SB from the inverter **562**, the output signal SC from the AND circuit **563**, and the light emission trigger signal SD from the delay circuit **564**.

Detection pulses **501** to **506** in the passage timing signal SA can serve as detection signals indicating that a target has been detected. The detection pulses **501** and **503** to **505** can be pulses generated due to a desired target **27** being detected. On the other hand, the detection pulses **502** and **506** can be pulses generated due to targets that are different from the desired target **27** being detected. For example, the detection pulse **502** can be a pulse generated due to a target whose output is too early being detected, and the detection pulse **506** can be a pulse generated due to a satellite being detected.

As described above, in the case where the targets **27** are being supplied correctly, the time interval T of the detection pulses in the passage timing signal SA can be within the permissible range. In other words, Tmin≤T≤Tmax can hold true. The light emission trigger pulses in the light emission trigger signal SD can also be generated at the same cycle.

Tmin can be a minimum permissible value for the time interval of the light emission trigger. Tmax can be a maximum permissible value for the time interval of the light emission trigger.

On the other hand, as described above, the time interval T of the detection pulses in the passage timing signal SA can become shorter than Tmin or longer than Tmax due to target generation abnormalities. In FIG. **7**, the time interval T between the detection pulse **501** and the detection pulse **502** can be less than Tmin. Likewise, the time interval T between the detection pulse **505** and the detection pulse **506** can be less than Tmin. As will be described later, the light emission trigger signal generation unit **552** can generate the light emission trigger signal SD so that the output interval of the light emission trigger does not become less than Tmin.

The detection pulse **501** in the passage timing signal SA can have a pulsewidth of Tw. Tw is a pulsewidth of a pulse generated when targets **27** that have been correctly generated are detected. The output signal of the one-shot circuit **561** may change from OFF to ON at the falling edge of the detection pulse **501**. The inverter output signal SB may be a signal obtained by inverting the output signal from the one-shot circuit **561**. The inverter output signal SB may change from ON to OFF at the falling edge of the detection pulse **501**.

The falling edge of the detection pulse **502** in the passage timing signal SA can be present while the inverter output signal SB is OFF. Upon detecting the falling edge of the input signal, the one-shot circuit **561** may reset a counter value for the pulsewidth Tsh. In other words, the pulsewidth Tsh of the output signal from the one-shot circuit **561** can be equivalent to an amount of time from the falling edge of the input signal SA immediately before.

A relationship of Tsh=Tmin−Tw, for example, may hold true for Tsh, Tmin, and Tw. The pulsewidth Tsh may be a value set in advance by a designer. The designer may determine Tmin and Tw in accordance with the system configuration, and may then determine Tsh based on those values.

The output signal from the one-shot circuit **561** may change from ON to OFF when a time equivalent to Tsh has passed from the falling edge of the detection pulse **502**. In other words, the inverter output signal SB may change from OFF to ON when a time equivalent to Tsh has passed from the falling edge of the detection pulse **502**. An amount of time from the falling edge of the detection pulse **502** to a rising edge of a pulse **507** in the inverter output signal SB may be equivalent to Tsh.

The AND circuit output signal SC can be ON when both the inverter output signal SB and the passage timing signal SA are ON. Accordingly, a pulse **510** corresponding to the detection pulse **502** need not be generated. Likewise, the light emission trigger pulse **515** of the light emission trigger signal corresponding to the pulse **510** in the AND circuit output signal SC need not be generated.

The detection pulse **503** in the passage timing signal SA can be outputted while the inverter output signal SB is ON.

Accordingly, a pulse **511** of the AND circuit output signal SC can be generated from the detection pulse **503**.

Alight emission trigger pulse **516** of the light emission trigger signal SD can be generated from the pulse **511** in the AND circuit output signal SC. The light emission trigger pulse **516** can be delayed from the pulse **511** in the AND circuit output signal SC by the delay circuit **564**, by the delay time td.

The inverter output signal SB may change from OFF to ON when a time equivalent to Tsh has passed from the falling edge of the pulse **507**. An amount of time from the falling edge of the pulse **507** to the rising edge of a pulse **508** in the inverter output signal SB may be equivalent to Tsh. The inverter output signal SB may change from ON to OFF and form the falling edge of the pulse **508** at the falling edge of the pulse **504** in the passage timing signal SA.

The pulse **504** in the passage timing signal SA can be outputted during the time when the inverter output signal SB is ON. Accordingly, a pulse **512** of the AND circuit output signal SC can be generated from the pulse **504**.

Alight emission trigger pulse **517** of the light emission trigger signal SD can be generated from the pulse **512** in the AND circuit output signal SC. The light emission trigger pulse **517** can be delayed from the pulse **512** in the AND circuit output signal SC by the delay circuit **564**, by the delay time td.

A relationship among the pulses **505**, **509**, **513**, and **518** can be the same as a relationship among the pulses **504**, **508**, **512**, and **517**. A relationship among the pulse **506**, a pulse **514** that is not present, and a pulse **519** that is not present can be the same as a relationship among the pulse **502**, a pulse **510** that is not present, and a pulse **515** that is not present.

Effect

According to the aforementioned configuration, the light emission trigger pulse can be suppressed from being outputted in the case where the time interval T of the detection pulses of the targets (droplets) is less than a minimum permissible value Tmin. As a result, a drop in the pulse energy and a change in the pulsewidth of the pulse laser beam outputted from the laser apparatus **3** can be suppressed. This in turn makes it possible to suppress fluctuations in the pulse energy of the EUV light and suppress the laser apparatus **3** from being damaged.

Other Configuration Example

FIGS. **8** and **9** illustrate an example of another configuration according to the first embodiment. The following descriptions will focus primarily on points that are different from the configuration example described with reference to FIGS. **6** and **7**. FIG. **8** schematically illustrates another example of the configuration of the laser controller **55** and the laser apparatus **3**. FIG. **9** is an example of timing charts indicating signals in the light emission trigger signal generation unit **552** according to the configuration example shown in FIG. **8**.

Configuration

As shown in FIG. **8**, the light emission trigger signal generation unit **552** may include an AND circuit **566**, a timer **567**, an RS flip-flop **568**, and a falling edge detection circuit **569** instead of the one-shot circuit **561** and the inverter **562** indicated in the configuration example shown in FIG. **6**. The light emission trigger controller **551** may set a set time in the timer **567** using a timer setting signal ST. The set time may be Tmin.

An input of the falling edge detection circuit **569** may be connected to an output of the light emission trigger controller **551**. The falling edge detection circuit **569** may receive the passage timing signal SA from the light emission trigger controller **551**. The falling edge detection circuit **569** may output a pulse having a comparatively short pulsewidth in response to the falling edge of the input signal.

One input of the AND circuit **566** may be connected to an output of the falling edge detection circuit **569**. Another input of the AND circuit **566** may be connected to an inverted Q terminal serving as an inverted output of the RS flip-flop **568**. An input of the timer **567** may be connected to an output of the AND circuit **566**.

The timer **567** may start measuring time upon detecting the rising edge of the input signal as a trigger for starting time measurement. The timer **567** may output a pulse when the set time has passed after the rising edge of the input signal. The set time may be Tmin. Upon detecting the rising edge of the input signal while measuring the time, the timer **567** may reset the time measurement value and begin measuring the time again.

An S terminal serving as a set input of the RS flip-flop **568** may be connected to the output of the falling edge detection circuit **569**. An R terminal serving as a reset input of the RS flip-flop **568** may be connected to an output of the timer **567**. The inverted output of the RS flip-flop **568** may be connected to one of the inputs of the AND circuit **563**. An inverted output signal SF from the RS flip-flop **568** may be inputted to the AND circuit **563** and the AND circuit **566**.

Operation

When a target is detected, the light emission trigger controller **551** may receive the passage timing signal SA and output a detection pulse. The RS flip-flop **568** may output an ON signal, corresponding to the detection pulse, to the AND circuit **563**. The AND circuit **563** may generate a pulse based on the ON signal from the RS flip-flop **568** and the pulse in the passage timing signal SA, and may output the generated pulse to the delay circuit **564**.

The timer **567** may start measuring time in response to the detection pulse in the passage timing signal SA. While the timer **567** is measuring time, the RS flip-flop **568** may hold the OFF signal at the inverted output regardless of whether the input signal at the set input is ON or OFF. Accordingly, while the timer **567** is measuring time, the AND circuit **563** and the delay circuit **564** may not generate the light emission trigger pulse even if a target is detected and the detection pulse in the passage timing signal SA is inputted.

When the measured time reaches the set time, the timer **567** may output a pulse. In response to a reset input signal changing from OFF to ON, the RS flip-flop **568** may change the inverted output signal inputted to the AND circuit **563** from OFF to ON. Thereafter, the AND circuit **563** and the delay circuit **564** may generate and output the light emission trigger pulse when the detection pulse in the passage timing signal SA is inputted. Furthermore, the timer **567** may start measuring time.

An example of operations performed by the light emission trigger signal generation unit **552** according to this example will be described with reference to the block diagram in FIG. **8** and the timing chart in FIG. **9**. As shown in FIG. **8**, the light emission trigger controller **551** may receive the passage timing signal SA and output the detection pulse **501** to the falling edge detection circuit **569** and the AND circuit **563**. The inverted output signal SF from the RS flip-flop **568** prior to a change may be ON at the falling edge of the detection pulse **501**.

The AND circuit **566** may receive the inverted output signal SF from the RS flip-flop **568** and the output signal from the falling edge detection circuit **569**. The inverted output signal SF from the RS flip-flop **568** prior to a change may be ON at the falling edge of the detection pulse **501**.

The falling edge detection circuit **569** may detect the falling edge of the detection pulse **501** and output a pulse **701**. In other words, the output signal from the falling edge detection circuit **569** can change from OFF to ON. Accordingly, the AND circuit **566** can change its output signal from OFF to ON.

The timer **567** may start measuring time upon detecting a rising edge of the output signal from the AND circuit **566**. The output signal from the timer **567** may be OFF while the timer **567** is measuring time. In other words, the reset input signal of the RS flip-flop **568** may be OFF at the falling edge of the pulse **501**.

A set input signal of the RS flip-flop **568** maybe an output signal SG from the falling edge detection circuit **569**. Accordingly, the set input signal SG of the RS flip-flop **568** can change from OFF to ON at the falling edge of the detection pulse **501**. As a result, the inverted output signal SF of the RS flip-flop **568** can change from ON to OFF.

The detection pulse **502** may be inputted before the time Tmin has passed from the pulse **501**. The falling edge detection circuit **569** may detect the falling edge of the detection pulse **502** and output a pulse **702**. The set input signal of the RS flip-flop **568** can change from OFF to ON.

The reset input signal of the RS flip-flop **568** is OFF, and the RS flip-flop **568** can hold the inverted output signal SF at OFF. Accordingly, the pulse **510** in the AND circuit output signal SC and the light emission trigger pulse **515** in the light emission trigger signal SD that correspond to the detection pulse **502** may not be generated.

The timer **567** may output a pulse when Tmin has passed from the falling edge of the detection pulse **501**. The reset input signal of the RS flip-flop **568** can change from OFF to ON. At this time, the set input signal of the RS flip-flop **568** can be OFF. The inverted output signal SF of the RS flip-flop **568** can change from OFF to ON, as indicated by a rising edge **707**. Thereafter, the set input signal of the RS flip-flop **568** can change from ON to OFF when the detection pulse of the passage timing signal SA is inputted.

After the inverted output signal SF of the RS flip-flop **568** has changed from OFF to ON, the pulse **503** of the passage timing signal SA may be inputted. Because the inverted output signal SF of the RS flip-flop **568** is ON, the AND circuit **563** may generate the pulse **511** from the pulse **503** and output the generated pulse **511**.

The delay circuit **564** may generate the light emission trigger pulse **516**, which is delayed from the pulse **511** by the delay time td, based on the pulse **511** in the AND circuit output signal SC, and may output the generated light emission trigger pulse **516** to the laser apparatus **3**.

In FIG. **9**, a relationship among the pulses **504**, **704**, **512**, and **517** and the operations performed by the light emission trigger signal generation unit **552** with respect to the generation of these pulses may be the same as with the pulses **503**, **703**, **511**, and **516**. Likewise, a relationship among the pulses **505**, **705**, **513**, and **518** and the operations performed by the light emission trigger signal generation unit **552** with respect to the generation of these pulses may be the same as with the pulses **503**, **703**, **511**, and **516**.

Furthermore, a relationship among the pulses **506**, **706**, the pulse **514** that is not present, and the pulse **519** that is not present, and the operations performed by the light emission trigger signal generation unit **552** with respect to the generation of these pulses, may be the same as with the pulses **502**, **702**, the pulse **510** that is not present, and the pulse **515** that is not present.

Effect

According to the aforementioned configuration, the light emission trigger pulse can be suppressed from being outputted in the case where the time interval T of the detection pulses of the targets is less than the minimum permissible value Tmin. As a result, a drop in the pulse energy and a change in the pulsewidth of the pulse laser beam outputted from the laser apparatus **3** can be suppressed. This in turn makes it possible to suppress fluctuations in the pulse energy of the EUV light and suppress the laser apparatus **3** from being damaged.

In the aforementioned configuration, after the light emission trigger pulse corresponding to a detection pulse has been generated, the next light emission trigger pulse can be generated in response to the detection pulse that occurs immediately after Tmin, which is set in the timer, has passed following the first detection pulse. Accordingly, the time interval of the light emission trigger pulse can be suppressed from becoming too long.

5.2 Second Embodiment

A second embodiment will be described with reference to FIGS. **10** and **11**. The following will focus primarily on differences from the first embodiment. In addition to the light emission trigger pulse outputted in response to the detection of a target including satellites, the laser controller **55** according to the second embodiment may generate a dummy light emission trigger pulse and output the dummy light emission trigger pulse to the laser apparatus **3**. Through this, the stability of the pulse laser beam outputted from the laser apparatus **3** can be improved.

Configuration

FIG. **10** schematically illustrates an example of the configuration of the laser controller **55** and the laser apparatus **3** according to the second embodiment. In addition to the configuration shown in FIG. **6**, the light emission trigger controller **551** may include OR circuits **575** and **577** and a timer **576**.

The timer **576** may output a pulse when a set amount of time has passed following the detection of a measurement start trigger. The light emission trigger controller **551** may set a set time in the timer **576** using a timer setting signal ST**2**. The set time may be, for example, a maximum permissible time interval Tmax for the light emission trigger pulse outputted to the laser apparatus **3**.

The timer **576** may start measuring time in response to the rising edge of an input signal serving as the measurement start trigger, for example. Upon detecting the measurement start trigger while measuring the time, the timer **576** may reset the measurement time and then start the time measurement again.

One input of the OR circuit **575** may be connected to an output of the light emission trigger controller **551**, and another input of the OR circuit **575** may be connected to an output of the timer **576**. The passage timing signal SA may be inputted to the OR circuit **575** from the light emission trigger controller **551**. An input of the timer **576** may be connected to an output of the OR circuit **575**.

One input of the OR circuit **577** may be connected to the output of the light emission trigger controller **551**, and another input of the OR circuit **577** may be connected to the output of the timer **576**. The passage timing signal SA may be inputted to the OR circuit **577** from the light emission trigger controller **551**. An output of the OR circuit **577** may be connected to the input of the one-shot circuit **561** and an input of the AND circuit **563**.

As shown in FIG. **10**, a former-stage circuit configured of the OR circuits **575** and **577** and the timer **576** and a latter-stage circuit configured of the one-shot circuit **561**, the inverter **562**, and the AND circuit **563** may be connected in series.

Operation

Operations performed by the former-stage circuit configured of the OR circuits **575** and **577** and the timer **576** will be described here. Operations performed by the latter-stage circuit are as described in the first embodiment with reference to FIGS. **6** and **7**. The former-stage circuit configured of the OR circuits **575** and **577** and the timer **576** may generate a dummy detection pulse and output the dummy detection pulse to the latter-stage circuit when the set time set in the timer **576** has passed from the previous detection pulse in the passage timing signal SA. Here, "dummy detection pulse" refers to a pulse generated without correspondence to the detection of a target including satellites.

FIG. **11** is an example of timing charts indicating signals in the light emission trigger signal generation unit **552**. Specifically, FIG. **11** is an example of timing charts for the passage timing signal SA, an output signal SH from the OR circuit **577**, the output signal SC from the AND circuit **563**, and the light emission trigger signal SD.

When the detection pulse **901** of the passage timing signal is inputted, the OR circuit **577** may output a pulse **905** in the output signal SH. In the latter-stage circuit, the AND circuit **563** may output a pulse **910**, corresponding to the pulse **905**, in the output signal SC. The delay circuit **564** may output the light emission trigger pulse **915** in which the pulse **910** is delayed.

The timer **576** may receive the detection pulse **901** via the OR circuit **575**. The timer **576** may start measuring the set time Tmax from the rising edge of the detection pulse **901**. Upon receiving a new pulse during the time measurement, the timer **576** may reset the measurement time and then start the time measurement again.

In the case where a new detection pulse in the passage timing signal SA is not inputted by the time the timer **576** finishes measuring the time Tmax, the timer **576** may output a pulse when the time measurement ends. The pulse from the timer **576** can be the dummy detection pulse.

The OR circuit **577** may output a pulse **906** corresponding to the dummy detection pulse from the timer **576**. In the latter-stage circuit, the AND circuit **563** may output a pulse **911**, corresponding to the pulse **906**, in the output signal SC. The delay circuit **564** may output a dummy light emission trigger pulse **916**, in which the pulse **911** is delayed, as a dummy light emission trigger.

A relationship among the pulses **902**, **907**, **912**, and **917** and the operations performed by the light emission trigger signal generation unit **552** with respect to the generation of these pulses may be the same as with the pulses **901**, **905**, **910**, and **915**.

Effect

As described in the first embodiment with reference to FIGS. **6** and **7**, the one-shot circuit **561**, the inverter **562**, and the AND circuit **563** in the aforementioned configuration can forgo outputting light emission trigger pulses corresponding to some target detection pulses. Through this, the time interval of the light emission trigger pulses can be suppressed from dropping below the minimum permissible value.

On the other hand, the OR circuits **575** and **577** and the timer **576** in the aforementioned configuration can generate the dummy light emission trigger pulse when the predetermined amount of time has passed from the output of the previous light emission trigger pulse. Through this, the time interval of the light emission trigger pulses outputted to the laser apparatus **3** can be suppressed from exceeding the maximum permissible value. Thus, according to the configuration described in the present embodiment, the time interval T of the light emission trigger pulses can be held between the maximum permissible value and the minimum permissible value.

Note that in the aforementioned exemplary configuration, the latter-stage circuit that suppresses the time interval of the light emission trigger pulses from dropping below the minimum permissible value may be omitted. Even according to such a configuration, the time interval of the light emission trigger pulses can be held within a range that is no greater than the maximum permissible value. The latter-stage circuit may have the configuration illustrated in FIG. **8**.

5.3 Third Embodiment

A third embodiment will be described with reference to FIGS. **12** and **13**. The following will focus primarily on differences from the second embodiment. The EUV light generation system **11** according to the present embodiment may block a pulse laser beam outputted in accordance with the dummy light emission trigger pulse. Through this, an undesirable pulse laser beam resulting from the dummy light emission trigger pulse can be suppressed from irradiating the plasma generation region **25**.

Configuration

FIG. **12** schematically illustrates an example of the configuration of the laser controller **55** and the laser apparatus **3** according to the third embodiment. In addition to the configuration shown in FIG. **10**, the light emission trigger controller **551** may include a one-shot circuit **581** and an inverter **582**. In addition to the configuration shown in FIG. **10**, the laser apparatus **3** may include an optical shutter **355**.

An input of the one-shot circuit **581** may be connected to the output of the timer **576**. An output of the one-shot circuit **581** may be connected to an input of the inverter **582**. An output of the inverter **582** may be connected to an input of the optical shutter **355**.

Upon detecting the rising edge of an input signal, the one-shot circuit **581** may output a pulse having a pulsewidth Tsh**2**. The pulsewidth Tsh**2** can indicate a time for which the pulse laser beam is to be blocked. The pulsewidth Tsh**2** may have a length equivalent to greater than or equal to an amount of time from when the rising edge is inputted to the one-shot circuit **581** to when the output of a pulse laser beam from the amplifier **354** resulting from the dummy light emission trigger pulse stops.

A value of the pulsewidth Tsh**2** may be set in the one-shot circuit **581** in advance. The light emission trigger controller **551** may set the value of the pulsewidth Tsh**2** in the one-shot circuit **581**.

The laser apparatus **3** may include the optical shutter **355**, disposed in the optical path of the pulse laser beam generated by the master oscillator **351**. The optical shutter **355** maybe disposed in, for example, the optical path of the pulse laser beam amplified by and outputted from the amplifier **354**. Alternatively, the optical shutter **355** maybe disposed in the optical path of the pulse laser beam between the master oscillator **351** and the amplifier **352**, between the amplifier **352** and the amplifier **353**, or between the amplifier **353** and the amplifier **354**.

The optical shutter **355** may block the pulse laser beam by absorbing or reflecting the pulse laser beam. For example, the optical shutter **355** may switch the optical path of the pulse laser beam between a first optical path and a second optical path (not shown) by switching between transmitting and reflecting the pulse laser beam.

The first optical path may be an optical path through which the pulse laser beam is focused at the plasma generation region **25**. The second optical path may be an optical path through which the pulse laser beam passes outside the plasma generation region **25** and is absorbed in a laser damper (not shown). The optical shutter **355** may open and close the optical path to the plasma generation region **25** by switching the optical path of the pulse laser beam in this manner.

When the optical shutter **355** is open, the pulse laser beam can pass through the optical shutter **355** and advance along the first optical path to the plasma generation region **25**. When the optical shutter **355** is closed, the pulse laser beam can be reflected by the optical shutter **355** and advance along the second optical path. The optical shutter **355** may be open when a control signal to the optical shutter **355** is ON, and may be closed when the control signal to the optical shutter **355** is OFF. The pulse laser beam can be blocked when the optical shutter **355** is closed.

The optical shutter **355** may have any configuration. For example, the optical shutter **355** may be configured including a Pockels cell and a polarizer. The Pockels cell can function as a $\lambda/2$ plate under an applied voltage. The optical shutter **355** may be configured including an acousto-optic device and a piezoelectric element. The acousto-optic device may diffract the pulse laser beam in accordance with applied vibrations.

Operation

As described in the second embodiment, the timer **576** may output a pulse in the case where the detection pulse interval T in the passage timing signal is greater than Tmax. The pulse can be the dummy detection pulse.

The one-shot circuit **581** may receive the dummy detection pulse from the timer **576**. The one-shot circuit **581** may output a pulse having the pulsewidth Tsh**2** in response to the rising edge of the dummy detection pulse. The inverter **582** may invert and output the signal from the one-shot circuit **581**.

The inverter **582** may output, to the optical shutter **355**, a pulse obtained by inverting the pulse from the one-shot circuit **581** in an optical shutter control signal SK. The inverted pulse inputted to the optical shutter **355** can have the pulsewidth Tsh**2**. The optical shutter **355** may be closed for the duration of the pulsewidth Tsh**2** in which the inverted pulse is being received. The transmission of the pulse laser beam can be suppressed by the closed optical shutter **355**.

The dummy light emission trigger based on the dummy detection pulse from the timer **576** can be inputted to the master oscillator **351**. The master oscillator **351** can emit the pulse laser beam in response to the inputted dummy light emission trigger pulse. The pulse laser beam from the master oscillator **351** can be amplified by the amplifiers **352** to **354**, and the amplified pulse laser beam can then be outputted from the amplifier **354**. The optical shutter **355** can be closed in accordance with the optical shutter control signal SK from the inverter **582**, and can suppress the amplified pulse laser beam from the amplifier **354** from passing.

On the other hand, in the case where the detection pulse interval T in the passage timing signal SA is less than or equal to Tmax, the optical shutter control signal SK can be ON, without the dummy detection pulse being outputted from the timer **576**. In other words, the optical shutter **355** can be open, and the amplified pulse laser beam from the amplifier **354** can pass through the optical shutter **355**.

FIG. **13** is an example of timing charts indicating signals in the light emission trigger signal generation unit **552** and pulse laser beams in the laser apparatus **3**. In addition to the timing charts indicated in FIG. **11**, FIG. **13** indicates timing charts of a pulse laser beam LA outputted from the master oscillator **351**, the control signal SK inputted to the optical shutter **355**, and a pulse laser beam LB outputted from the laser apparatus **3** to the exposure apparatus **6**.

In FIG. **13**, the timing charts aside from the timing charts for the master oscillator-emitted pulse laser beam LA, the optical shutter control signal SK, and the output pulse laser beam LB are the same as the timing charts indicated in FIG. **11**. The master oscillator **351** may output laser beam pulses **1101** to **1105** in response to the light emission trigger pulses **915** to **919**, respectively.

The pulse **906** in the OR circuit output signal SH, the pulse **911** in the AND circuit output signal SC, the dummy light emission trigger pulse **916** in the light emission trigger signal SD, and the laser beam pulse **1102** in the master oscillator-emitted pulse laser beam LA can be generated in accordance with the dummy detection pulse from the timer **576**.

The optical shutter control signal SK can change from ON to OFF in accordance with the dummy detection pulse from the timer **576**. The time for which the optical shutter control signal SK is OFF can be equivalent to the pulsewidth Tsh**2** of the one-shot circuit **581**. The laser beam pulse **1102** in the master oscillator-emitted pulse laser beam LA can be outputted while the optical shutter control signal SK is OFF, and can thus be blocked by the optical shutter **355**. Accordingly, the output laser beam pulse from the laser apparatus **3** resulting from the laser beam pulse **1102** from the master oscillator **351** can be suppressed.

Effect

According to the configuration described in the present embodiment, in the case where the detection pulse interval T in the passage timing signal SA is greater than Tmax, the master oscillator **351** can emit the pulse laser beam due to the dummy light emission trigger pulse. As a result, fluctuations in the pulse laser beam from the master oscillator **351** can be suppressed.

Furthermore, the pulse laser beam outputted from the master oscillator **351** in response to the dummy light emission trigger pulse can be blocked by the optical shutter. As a result, the pulse laser beam can be suppressed from irradiating the plasma generation region **25** in response to the dummy light emission trigger pulse. Through this, an increase in debris caused by the pulse laser beam outputted in response to the dummy light emission trigger pulse can be suppressed. In the case where gas present in the chamber **2**, satellites of targets that have not been detected, and so on are present in the plasma generation region **25**, these items can produce plasma when irradiated with the pulse laser beam, which in turn can produce debris. The debris may be fast ions scattered from the plasma, scattered particles such as neutral particles, or the like, and can spatter on or adhere to optical components such as the EUV collector mirror **23**, causing a drop in the optical performance thereof.

5.4 Fourth Embodiment

A fourth embodiment will be described with reference to FIG. **14**. The following will focus primarily on differences from the third embodiment. The laser apparatus **3** according to the present embodiment may include a pre-pulse laser device in addition to a main laser device.

The EUV light generation system **11** according to the present embodiment may block a main pulse laser beam outputted from the main laser device in response to the dummy light emission trigger pulse as well as a pre-pulse laser beam outputted from the pre-pulse laser device in response to the dummy light emission trigger pulse. Through this, an undesirable pulse laser beam resulting from the dummy light emission trigger pulse can be suppressed from irradiating the plasma generation region **25**.

Configuration

FIG. **14** schematically illustrates an example of the configuration of the laser controller **55** and the laser apparatus **3** according to the fourth embodiment. In addition to the configuration shown in FIG. **12**, the laser apparatus **3** may include a pre-pulse laser device **361**, an optical shutter **362**, a high-reflecting mirror **363**, and a dichroic mirror **364**. The pre-pulse laser device **361** may be a solid-state laser device such as a YAG laser device.

In the present embodiment, the master oscillator **351** may be referred to as a main pulse laser device. An apparatus configured by and including the master oscillator **351**, the amplifiers **352**, **353**, and **354**, and the optical shutter **355** will be referred to as a main pulse laser apparatus. A laser beam emitted from the master oscillator **351** and a beam obtained by amplifying that laser beam may be referred to as the main pulse laser beam.

Referring to FIG. **14**, the optical shutter **355** may be disposed in an optical path between the master oscillator **351** and the amplifier **352**. The dichroic mirror **364** may be disposed in the optical path of the main pulse laser beam. The main pulse laser beam may be incident on the dichroic mirror **364**. The dichroic mirror **364** may allow the main pulse laser beam to pass through, at a high level of transmissibility, toward an optical path of the exposure apparatus **6**.

The pre-pulse laser device **361** may output the pre-pulse laser beam. The pre-pulse laser beam may contain a different wavelength component from a wavelength component contained in the main pulse laser beam. The optical shutter **362** may be disposed in an optical path of the pre-pulse laser beam. Like the optical shutter **355**, the optical shutter **362** may block the pre-pulse laser beam by switching the optical path of the pre-pulse laser beam in accordance with the optical shutter control signal SK.

The high-reflecting mirror **363** may be disposed in the optical path of the pre-pulse laser beam. The high-reflecting mirror **363** may reflect the pre-pulse laser beam at a high level of reflectance. The pre-pulse laser beam reflected by the high-reflecting mirror **363** may be incident on the dichroic mirror **364**. The dichroic mirror **364** may reflect the pre-pulse laser beam, at a high level of reflectance, toward the optical path of the exposure apparatus **6**. The main pulse laser beam and the pre-pulse laser beam can both be conducted to the plasma generation region **25** as a result. The dichroic mirror **364** may be disposed so that the optical paths of the pre-pulse laser beam and the main pulse laser beam substantially match.

In addition to the configuration shown in FIG. **12**, the light emission trigger controller **551** may include a delay circuit **584**. An input of the delay circuit **584** may be connected to the output of the delay circuit **564**. An output signal from the delay circuit **584** may be inputted to the master oscillator **351**.

The output signal from the delay circuit **564** may be inputted to the pre-pulse laser device **361**. A delay time of the delay circuit **584** can be equivalent to the time of a delay between the input of the light emission trigger to the pre-pulse laser device **361** and the input of the light emission trigger to the main pulse laser device. The light emission trigger controller **551** may set a predetermined delay time in the delay circuit **584**.

An output of the inverter **582** may be connected to inputs of both the optical shutters **355** and **362**. The same optical shutter control signal SK may be inputted to both the optical shutters **355** and **362**. The optical shutter control signal inputted to the optical shutter **355** may be delayed from the optical shutter control signal inputted to the optical shutter **362** by the predetermined delay time.

Operation

As described in the second embodiment, the timer **576** may output a pulse in the case where the detection pulse interval T in the passage timing signal is greater than Tmax. The pulse can be the dummy detection pulse.

The one-shot circuit **581** may receive the dummy detection pulse from the timer **576**. The one-shot circuit **581** may output a pulse having the pulsewidth Tsh**2** in response to the rising edge of the dummy detection pulse. The inverter **582** may invert and output the signal from the one-shot circuit **581**.

The inverter **582** may output, to the optical shutters **362** and **355**, a pulse obtained by inverting the pulse from the one-shot circuit **581** in the optical shutter control signal SK. The inverted pulse inputted to the optical shutters **362** and **355** can have the pulsewidth Tsh**2**.

The optical shutters **362** and **355** may be closed for the duration of the pulsewidth Tsh**2** in which the inverted pulse is being received. The transmission of the main pulse laser beam and the pre-pulse laser beam can be suppressed by the closed optical shutters **362** and **355**. In other words, the main pulse laser beam and the pre-pulse laser beam can be blocked.

The dummy light emission trigger pulse corresponding to the dummy detection pulse from the timer **576** can be inputted to the pre-pulse laser device **361** and the master oscillator **351**. The dummy light emission trigger pulse inputted to the master oscillator **351** may be delayed, by the delay circuit **584**, from the dummy light emission trigger pulse inputted to the pre-pulse laser device **361**.

The pre-pulse laser device **361** can emit the pre-pulse laser beam in response to the inputted dummy light emission trigger pulse. The optical shutter **362** can be closed in accordance with the optical shutter control signal SK from the inverter **582**, and can suppress the pre-pulse laser beam from the pre-pulse laser device **361** from passing.

The master oscillator **351** can emit the main pulse laser beam in response to the inputted dummy light emission trigger pulse. The optical shutter **355** can be closed in accordance with the optical shutter control signal SK from the inverter **582**, and can suppress the main pulse laser beam from the master oscillator **351** from passing.

On the other hand, in the case where the detection pulse interval T in the passage timing signal SA is less than or equal to Tmax, the optical shutter control signal SK of the optical shutters **362** and **355** can be ON, without the dummy detection pulse being outputted from the timer **576**. In other words, the optical shutters **362** and **355** can be open, and the pulse laser beams from the pre-pulse laser device **361** and the master oscillator **351** can pass through the optical shutters **362** and **355**, respectively.

Effect

According to the configuration described in the present embodiment, in the case where the detection pulse interval T in the passage timing signal SA is greater than Tmax, the master oscillator **351** and the pre-pulse laser device **361** can emit the pulse laser beams in response to the dummy light emission trigger pulse. Through this, fluctuations in the pulse laser beams from the master oscillator **351** and the pre-pulse laser device **361** can be suppressed.

Furthermore, the pulse laser beams outputted from the master oscillator **351** and the pre-pulse laser device **361** in response to the dummy light emission trigger pulse can be blocked by the respective optical shutters. As a result, the pulse laser beam can be suppressed from irradiating the plasma generation region **25** in response to the dummy light emission trigger pulse. Through this, an increase in debris caused by the pulse laser beam outputted in response to the dummy light emission trigger pulse can be suppressed.

The above-described embodiments and the modifications thereof are merely examples for implementing the present disclosure, and the present disclosure is not limited thereto. Making various modifications according to the specifications or the like is within the scope of the present disclosure, and other various embodiments are possible within the scope of the present disclosure. For example, the modifications illustrated for particular ones of the embodiments can be applied to other embodiments as well (including the other embodiments described herein).

The configurations of the constituent elements illustrated in the drawings and described in the aforementioned embodiments are merely examples, and the constituent elements may have other configurations instead. The aforementioned constituent elements, functions, and so on may be partially or entirely realized through hardware, by appropriate electrical circuit design or the like. Likewise, the aforementioned constituent elements, functions, and so on may be realized through software, by a processor analyzing and executing programs that realize those respective functions.

The configuration of a given embodiment can be partially replaced with the configuration of another embodiment. The configuration of a given embodiment can be added to the configuration of another embodiment. Parts of the configurations of the respective embodiments can be removed or replaced with other configurations, and other configurations can be added thereto.

The terms used in this specification and the appended claims should be interpreted as "non-limiting." For example, the terms "include" and "be included" should be interpreted as "including the stated elements but not limited to the stated elements." The term "have" should be interpreted as "having the stated elements but not limited to the stated elements." Further, the modifier "one (a/an)" should be interpreted as "at least one" or "one or more."

What is claimed is:

1. An extreme ultraviolet light generation apparatus that generates extreme ultraviolet light by irradiating a target with a pulse laser beam and producing plasma, the apparatus comprising,

a chamber containing a plasma generation region irradiated by a pulse laser beam from a laser apparatus;

a target supply device configured to supply a plurality of targets consecutively to the plasma generation region in the chamber;

a target detection unit configured to detect a target outputted from the target supply device that has passed a predetermined position between the target supply device and the plasma generation region; and

laser control circuitry configured to control the laser apparatus,

the laser control circuitry including a light emission trigger generation circuit configured to generate a light emission trigger instructing a laser device included in the laser apparatus to emit a pulse laser beam, and output the generated light emission trigger to the laser apparatus,

the light emission trigger generation circuit including a first circuit configured to output a first signal that changes from OFF to ON after a first time has passed from a detection signal indicating target detection from the target detection unit, and a first AND circuit configured to output an AND signal of the first signal and the detection signal,

the light emission trigger generation circuit outputting the light emission trigger to the laser apparatus based on an output from the first AND circuit, and

the laser control circuitry outputting the light emission trigger to the laser apparatus in response to a next detection signal received immediately after the first time has passed following the detection signal.

2. The extreme ultraviolet light generation apparatus according to claim **1**, wherein the first circuit includes a falling detection circuit configured to detect falling of the detection signal from the target detection unit.

3. The extreme ultraviolet light generation apparatus according to claim **1**, wherein the emission trigger generation circuit includes a delay circuit configured to generate the light emission trigger based on the AND signal from the first AND circuit.

4. The extreme ultraviolet light generation apparatus according to claim **1**, wherein the laser control circuitry includes a light emission trigger control circuit configured to transfer the detection signal from the target detection unit to the first AND circuit.

5. An extreme ultraviolet light generation apparatus that generates extreme ultraviolet light by irradiating a target with a pulse laser beam and producing plasma, the apparatus comprising,

a chamber containing a plasma generation region irradiated by a pulse laser beam from a laser apparatus;

a target supply device configured to supply a plurality of targets consecutively to the plasma generation region in the chamber;

a target detection unit configured to detect a target outputted from the target supply device that has passed a predetermined position between the target supply device and the plasma generation region; and

laser control circuitry configured to control the laser apparatus,

the laser control circuitry including a light emission trigger generation circuit configured to generate a light emission trigger instructing a laser device included in the laser apparatus to emit a pulse laser beam, and output the generated light emission trigger to the laser apparatus,

the light emission trigger generation circuit including a first circuit configured to output a first signal that changes from OFF to ON after a first time has passed from a detection signal indicating target detection from the target detection unit, and a first AND circuit configured to output an AND signal of the first signal and the detection signal,

the light emission trigger generation circuit outputting the light emission trigger to the laser apparatus based on an output from the first AND circuit, and

the first circuit including a one-shot circuit configured to output a pulse of a predetermined pulse width in accordance with a detection signal from the target detection unit and an inverter configured to invert output from the one-shot circuit and output the inverted output to the first AND circuit.

6. An extreme ultraviolet light generation apparatus that generates extreme ultraviolet light by irradiating a target with a pulse laser beam and producing plasma, the apparatus comprising, a chamber containing a plasma generation region irradiated by a pulse laser beam from a laser apparatus;

a target supply device configured to supply a plurality of targets consecutively to the plasma generation region in the chamber;

a target detection unit configured to detect a target outputted from the target supply device that has passed a predetermined position between the target supply device and the plasma generation region; and

laser control circuitry configured to control the laser apparatus,

the laser control circuitry including a light emission trigger generation circuit configured to generate a light emission trigger instructing a laser device included in the laser apparatus to emit a pulse laser beam, and output the generated light emission trigger to the laser apparatus,

the light emission trigger generation circuit including a first circuit configured to output a first signal that changes from OFF to ON after a first time has passed from a detection signal indicating target detection from the target detection unit, and a first AND circuit configured to output an AND signal of the first signal and the detection signal,

the light emission trigger generation circuit outputting the light emission trigger to the laser apparatus based on an output from the first AND circuit, and

the first circuit including a timer to measure the first time and a second circuit configured to output an OFF signal to the first AND circuit while the timer measures the first time and an ON signal to the first AND circuit after the timer measures the first time.

7. The extreme ultraviolet light generation apparatus according to claim **6**, wherein the first circuit includes a falling detection circuit configured to detect falling of the detection signal from the target detection unit.

8. The extreme ultraviolet light generation apparatus according to claim **7**, wherein the first circuit includes a second AND circuit configured to output an AND signal to the timer based on the detection signal.

9. The extreme ultraviolet light generation apparatus according to claim **8**, wherein the second circuit is a flip-flop circuit.

10. The extreme ultraviolet light generation apparatus according to claim **9**, wherein the timer is configured to output the ON signal to the second circuit to invert output of the second circuit after the timer measures the first time.

11. The extreme ultraviolet light generation apparatus according to claim **10**, wherein the timer is configured to reset measurement of the first time upon detecting a next detection signal while the timer measures the first time.

12. The extreme ultraviolet light generation apparatus according to claim **10**, wherein the emission trigger generation circuit includes a delay circuit configured to generate the light emission trigger based on the AND signal from the first AND circuit.

13. The extreme ultraviolet light generation apparatus according to claim **10**, wherein the laser control circuitry includes a light emission trigger control circuit configured to transfer the detection signal from the target detection unit to the first AND circuit and output a time setting signal for setting the timer.

14. The extreme ultraviolet light generation apparatus according to claim **10**, wherein the falling detection circuit is configured to detect an edge of the detection signal.

15. The extreme ultraviolet light generation apparatus according to claim **7**, wherein the second circuit is a flip-flop circuit.

16. The extreme ultraviolet light generation apparatus according to claim **7**, wherein the timer is configured to output a signal for inverting output from the second circuit to the second circuit after the timer measures the first time.

17. The extreme ultraviolet light generation apparatus according to claim **7**, wherein the timer is configured to output the ON signal to the second circuit to invert output of the second circuit after the timer measures the first time.

18. The extreme ultraviolet light generation apparatus according to claim **6**, wherein the emission trigger generation circuit includes a delay circuit configured to generate the light emission trigger based on the AND signal from the first AND circuit.

19. The extreme ultraviolet light generation apparatus according to claim **6**, wherein the laser control circuitry includes a light emission trigger control circuit configured to transfer the detection signal from the target detection unit to the first AND circuit and output a time setting signal for setting the timer.

* * * * *